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ABSTRACT

These conference proceedings contain papers on practical applications of rehabilitation and assistive technology in vocational and educational situations as well as independent living settings. Most of the papers are two pages in length. The papers are organized into the following categories, with the number of papers in each category appearing in parentheses: personal transportation (2); electric wheelchair systems (5); computer access issues (6); aging (2); prosthetics, orthotics, and rehabilitation technology (13); interfacing power mobility and joystick controls (6); rural rehabilitation (3); information networking (5); selected alternative and augmentative communication issues (4); soft tissue pressure (6); computer hardware and expert systems software (5); functional neuromuscular stimulation for exercise and gait (6); robotics (12); quantitative assessment (12); sensory aids for the blind and deaf-blind (6); language processing in augmentative communication systems (5); computer-assisted design/computer-assisted manufacturing topics in orthotics/prosthetics (4); angle in space and seat back influences (6); evaluation of functional neuromuscular stimulation applications (6); technology transfer potpourri (6); new models (6); technology developments and augmentative communication application (5); contoured seating systems (6); computer applications (12); research analysis and survey results (5); efficient production in augmentative communication (5); clinical perspectives--mobility and communication (4); sensory aids for the deaf (5); and education and policy issues (8). Papers from poster sessions are also included. (JDD)

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RESNA'89

an interdisciplinary association for the advancement of rehabilitation and assistive technologies

PROCEEDINGS
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Technology
for the
Next Decade

June 25-30, 1989

New Orleans Marriott Hotel
New Orleans, Louisiana

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Jessica J. Presperin, OTR/L, MBA
Editor

Paul N. Hale, Jr, PhD
Conference Chair

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Foreword

RESNA is an interdisciplinary association for the advancement of rehabilitation and assistive technology. Its membership includes engineers and technicians, physicians, orthotists and prosthetists, therapists, special education and vocational education staff, vocational rehabilitation and service delivery personnel, and most importantly, consumer involvement. The 12th Annual Conference is a reflection of that organization's commitment to provide a variety of formats through which individuals can meet, exchange information and grow.

This year's theme, "Technology for the Next Decade," places emphasis on the practical, applied applications of technology in vocational and educational situations as well as independent living settings. The RESNA membership is extremely diverse and the common thread between these groups is the recognition of the important contribution that rehabilitation technology can make in the lives of persons with disabilities. This conference and its proceedings are dedicated to the sharing of knowledge about rehabilitation technology so we can meet the challenges that will face us in the next decade.

We would like to thank all of the contributors to this publication.

Richard A. Foulds, PhD
President

Paul N. Hale, Jr, PhD
Conference Chair

Preface

Welcome to RESNA '89.

This year, 1989, brings us to an energetic state as we close the 80s and prepare for the last decade before 2000. Rehabilitation Technology remains at the forefront, attempting to increase the independence of those of us with physical or sensory challenges.

Despite budgetary cuts throughout the nation, researchers, clinicians, and consumers continue to promote the importance of rehabilitation technology into the future. The RESNA membership illustrates this energy. This volume contains the proceedings of the scientific papers presented as part of the 1989 RESNA Annual Conference held in New Orleans.

A number of individuals volunteered to make this conference the success I presume it to be. Under the leadership of Tony Langton, Meetings Committee Chair, the Meetings Committee was formed. Tony assisted the committee and the local conference planners in bringing together the 1989 conference, as well as establishing guidelines for future conference use.

Paul Hale and his associates organized the conference at the local level, creatively bringing the atmosphere of New Orleans' jazz, cooking, and hospitality to the RESNA participants. The SIG Chairs and their colleagues reviewed papers, encouraged speakers for morning seminars and instructional courses, and organized special sessions.

In an attempt to comply with recommendations, the following additions were made to the conference agenda:

1. An unopposed meeting was scheduled for SIG-01 Service Delivery & Public Policy Issues.
2. An unopposed meeting time was scheduled to allow members to discuss Quality Assurance.
3. SIG meetings were staggered to allow members to participate in more than one meetings.
4. A three-hour block of time was alloted to SIG Chairs to provide an opportunity for networking, open forums, invited speakers, and formal sessions.

The arduous task of compiling the proceedings, finding rooms for all the presentations and meetings, registration, and bringing it all together goes to the RESNA professional staff. A special thanks to Susan Leone and Pat Horner for their consistent continuous energy.

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AUTOMATIC WHEELCHAIR INBOARD STORING

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ABSTRACT

Many disabled drivers using a wheelchair find it possible to install themselves behind the steering wheel of a vehicle but are then faced with the formidable task of trying to bring the wheelchair inboard! This paper describes the design of a device that will automatically bring a folded wheelchair inside the boundaries of a vehicle.

The device was successfully adapted to a variety of cars and the paper will review the design objectives and the detailed operation.

Being free to move and to travel over long distance is often than most, a convenience, disabled persons have still to discover. Even though efforts have been made, mobility of handicapped people is still a problem everywhere; very often handicapped people in wheelchair have still to rely, even for their most simple needs, on members of their immediate family or on the community whereas, given the technical means, they could be as self supporting and as mobile as most everyone.

Thus, in order to increase the mobility of disabled usually confined to wheelchairs, researchers at Ecole Polytechnique de Montréal have participated, in cooperation with industry, in the design and development of a low cost device that can be installed in most vehicles. This device allows handicapped people to bring their own wheelchair inside a vehicle, without any exterior help, any special strength or any special movement nor requirement as long as they can transfer, by themselves, from the wheelchair to the automobile seat and back. Operation of the device is through a simple switch located on the instrument panel of the vehicle.

The device was designed with flexibility, low maintenance, low cost and ease of operation in mind. It is intended for disabled people who have use of their upper limbs even if their lower limbs are not mobile.

DESIGN OBJECTIVES AND CRITERION

The device was designed to automatically bring an empty wheelchair inside a vehicle and conversely, to bring it out when required. The wheelchair operator needs to have upper limbs mobility since it is required for moving from wheelchair to vehicle seat and back and also, obviously for operation of the device and the vehicle. However, no particular strength or physical ability is required to operate the device.

Contrary to other devices, vehicle requirements are kept to a minimum and it only need to offer four doors and a fairly flat rear floor pan; this last requirement is usually met in most front wheel drive vehicles. Usually, the device can be fitted in even the smaller vehicle class and for example, a 1983 Honda Civic was fitted with the device.

DESCRIPTION AND MODE OF OPERATION

The device is made-up of two basic parts: the first one allows the sliding of the vehicle door to the rear and the second one picks up and brings the wheelchair inside the vehicle and conversely, brings it out again when required.

The first part was designed in order to allow normal opening of the door, by rotation around the hinges while also allowing a sliding motion of the door. This is accomplished through the use of a "U" shaped structure installed inside the driver's side rear door; this structure ties into the existing hinges and supports a sliding mechanism driven by an electric motor and chain drive on which the door can slide. The structure and drive are fitted between door panels. Two guiding shafts are used to support the door in order to lower friction forces and insure that it moves parallel to it's original position.

Thus, when the electric drive is not in operation, the door is opened in normal fashion by rotation around the original equipment hinges. When the drive is in used, for storing a wheelchair, the door panel first move out sufficiently to clear the side of the vehicle and then, slides to the rear.

Obvious benefits are manyfold in this mechanism that still allows normal operation of door and usual seating arrangement, when a wheelchair is not stored in the vehicle. On the other hand, sliding action of the door allows for a greater opening of the door area and thus eases chair loading. Also, since the original equipment hinges are still used, the vehicle still complies with the original requirements for side door strength. Actually, due to the added structure, the driver side rear door is stronger than the original equipment.

This structure must be made to measure to fit inside door panels depending on vehicle make but due to the simplicity of the design the task is fairly straightforward.

The second part of the device is the mechanical arm and wheelchair attachment that are used to bring and store the wheelchair inside the vehicle. Due to the fact that the rear seat can still be used, the wheelchair must first be folded back before it can be brought in the vehicle.

The mechanism is as follow: a rail is bolted through the floor in front of the bench seat. With the rail installed, but no wheelchair, the bench seat can still be used. A power screw driven trolley can travel on the rail and supports the DC actuator powering the mechanical arm used to pick-up the wheelchair. The actuator has a 100 mm (4") stroke and a 1100 N (250 lb) load capacity for a weight of only 45 N (10 lb). Due to the special guiding plates the arm, when coming out of it's storage position, climbs up and it's specially formed extremities mates with an adaptor plate affixed to each side of the wheelchair. This is the only modification that needs to be performed to the wheelchair. The extremities and adaptor plates are designed for stability while storing the wheelchair inside the vehicle and also, to restrain the wheelchair from moving, while the vehicle is underway and being submitted to various acceleration levels. The adaptor plates are designed to allow for variations in pick-up height due to various car model being used. Also, the extremities of the mechanical arm are designed so that they can accomodate various widths of wheelchairs, when folded. Thus the device is fairly universal and can be used without modifications on most vehicles and wheelchairs combinations; only the rail length is chosen in relation to vehicle width

Control of the device is through a joy stick and travel of the trolley is stopped by limit switches.

CONCLUSIONS

A fairly simple and very rugged, almost universal device was designed in order to automatically store a wheelchair inside a vehicle. The device can be used by most disabled people with upper limbs mobility. It does not require any special strength or movement from the operator and the vehicle only needs to have four doors and a fairly flat rear floor space. The device can be adapted to most cars, even smaller ones, and can take care of most wheelchairs with only minor modifications.

UNISTIK^{TM} VEHICLE CONTROLLER: CLINICAL EVALUATION AND PREDICTION OF DRIVING ABILITY

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ABSTRACT

The Unistik^{TM} vehicle controller is an adaptive control system added to the inside of a motor vehicle, which allows a driver to control all movement of the vehicle at highway speeds using only one hand (or other limb) on a single joystick. This study tested efficacy of driving for 22 subjects with various types of disability, with emphasis on prediction of driving ability by common clinical methods. Psychological testing, wheelchair skill evaluation, upper extremity sensory, muscle strengh and performance measurements were done, and the results were correlated with driving test scores.

INTRODUCTION

Unistik^{TM} involves a combination of technologies including microprocessor control and monitoring, digital and analog electronic circuitry, electro-servomotors, and mechanical actuators. This provides the sensitivity and reliability required for joystick control at highway speeds. A second, smaller joystick is installed with a wiring harness connected to operate the head lights, dimmer, wipers, turn signal, horn, door locks, CB radio, etc. Since movement of either joystick requires very little effort on the part of the driver, Unistik^{TM} is applicable as a vehicle control system for many severely disabled individuals.

METHODS

Subjects who were recruited to participate in the study were users of electric wheelchairs and unable to drive using other systems or were having difficulty with their present system. First, a mobility and wheelchair data base was collected and an initial detailed interview was done, targeting any symptoms of depression, seizure activity, heart arrythmias, or other contraindications to safe riving. Psychological tests performed included: (1) Mini-Mental Status Examination, (2)Tennessee Self Concept Scale, (3) Multiple Affect Adjective Check List, (4) Symptom Check List 90-R, and (5) Motor-Free Visual Perception Test.

A detailed upper extremity examination was performed on each subject, including (1) Manual Muscle Testing, (2) Strength of neck, shoulder, elbow wrist, and finger muscles, (3) Functional Grasp and Release (3) Nine Hole Peg Test (A standardized test which measures the time necessary to insert/remove nine standard pegs in a small pegboard), (4) Active Range of Motion, (5) Grip Strength, (6) Oppositional and Appositional Grip Strength, (7) Sensory Level to Pinprick, (8) Joint Proprioception, and (9)Stereognosis. In addition, a gross evaluation of upper extremity spasticity was performed and recorded in a standardized fashion. Wheelchair driving ability was evaluated for speed and accuracy on a standard course. A standard vision test and a written test covering driving laws were administered. All subjects who did not have a valid Drivers' License obtained a Washington Learners' Permit.

Initial behind-the-wheel training took place on a protected driving range. Controls were moved to the most easily accessible position for the particular driver, and the most effective driving interface was chosen. Because many of the subjects had limitations in neck mobility, the problem of side and rear visibility was addressed, and a full-view front mirror and side mirrors were used and adjusted to provide full visibility. The subject was then instructed in startup procedures, smooth acceleration, turns, stopping, backing, and maneuvering around obstacles. When it was determined that the subject was ready to "graduate" from the driving range a standard test was given, scoring each driver in a subjective but standard fashion in ten skill areas pertinent to driving ability. Following this test, the subjects were taken to surrounding city streets in residential and industrial neighborhoods. Driver Training on city streets was carried out in the usual manner. At the end of each session, the Driver Trainer completed a Progress Report noting the time behind the wheel, miles driven, and progress in a number of areas. This information was reviewed with the subject at the end of each session. An end point to driver training was determined by one of two conditions: (1) the subject was not making progress toward the goal of safe independent driving after 12 hours of training, or (2) the subject was deemed by the driver trainer to be competent in driving in traffic on city streets. At the time of termination of driver training, a standard road test was administered to each driver, which is identical to the Washington Drivers' License Road Test, and results were recorded. If it was deemed that administration of a road test would pose a danger to the subject and/or driver trainer, the road test was not done, and the score was recorded as "0".

RESULTS/CONCLUSIONS

The subject sample consisted of 22 people who completed the study. Fifteen of those had traumatic quadriplegia at the functional C5 level bilaterally or at the C4 level on one side and C5 on the other. There were two subjects with muscular dystrophy, two with post-polio paralysis, one with cerebral palsy, one with spinal muscular atrophy and two with quadriplegia as a result of syringomyelia.

It was found that those persons with Multiple Sclerosis, stroke and traumatic brain injury who had physical disabilities significant enough to require the Unistik™ system had, without exception, visual and/or cognitive impairments that would preclude safe driving. It was therefore concluded that in most cases Unistik™ is not an appropriate device for those who are paralyzed as a result of these conditions.

Vehicle performance was carefully monitored during this study. The vehicle was driven a total of 8,916 miles for the period of the study. During this time, the Unistik™ system functioned and responded invariably as designed.

Mean behind-the-wheel training time was 8.39 hours (St.Dev = 3.53, Range = 5.00 to 20.00) Mean miles traveled during behind-the-wheel training amounted to 50.8 miles (SD= 24.2, Range = 30.3 - 110.0) There was no correlation of hours and miles driven with driving range and road test scores.

Eight different "handle" interfaces were evaluated. The majority of subjects (17/22) used a malleable, padded U-shaped handle more easily than any of the others. Two subjects with significant hand deformities found that a simple stick was preferable, and two with the best hand function preferred a small ball. The tri-pin handle was not useful, and the t-shaped control was preferred by only one driver. No custom-molded hand interfaces or splints were necessary. For those drivers with good shoulder function (mostly traumatic quadriplegics), placement of the control boxes was easily accomplished in a fairly standard position on the left or right. However, those subjects who had very weak or non-functioning shoulder muscles could not use the controls in the positions possible to obtain with the mounting brackets. They seemed to require the joystick much closer to the body, and often in the midline.

Of the 22 subjects who finished the program, 17 progressed to the point of city/residential driving, and 15 were considered to have adequate (a score of 80 or above on the road test) skills to drive the vehicle independently and obtain a Washington Drivers' License. Of those 15 "successful drivers", 13 were had traumatic spinal cord injury, and two had muscular dystrophy. All but one of the drivers who had "passing" scores had driven before the onset of disability. Driving range scores were significantly lower for those who had not driven before.

Shoulder strength, particularly internal rotation, was the only muscle function measured which correlated with driving ability. Spasticity, sensory level and proprioception were not significant determinants of successful driving in these subjects.

As has been found repeatedly with other systems, the most precise way of predicting driving ability with the Unistik™ system is the preliminary assessment of vehicle control in the Driving Range. Driving performance on each sub-test of the Preliminary Test after an average of 1-1/2 hours of BTW training in each area of driving range skills correlated significantly with total road test scores and each driving sub-test.

In summary,this system seems to be an effective means of driving for a number of individuals with severe disabilities. From the results of this study, the Unistik™ system appears to be particularly readily adaptable for the traumatic C5 quadriplegic who has driven before the onset of disability. There were no critical malfunctions of the Unistiktm system during the 18-month evaluation period.

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DEPENDABILITY MODELING OF ELECTRIC WHEELCHAIR SYSTEMS

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ABSTRACT

This paper presents current results towards the development of a software system to facilitate the study of reliability, availability, and safety for electric wheelchair systems. The software package is aimed at supporting designers wishing to integrate dependability analysis with the design process of the entire wheelchair including both the electrical and mechanical components. Using the software, the designer is able to predict the dependability of a wheelchair system and to study the effect of different component characteristics on system dependability.

INTRODUCTION

An important link in the proper development of an improved electric wheelchair is the dependability analysis of the wheelchair design. Ideally, dependability analysis and wheelchair system design should be performed concurrently such that design decisions can be evaluated and their impact on wheelchair dependability determined. Various dependability modeling techniques have been developed for the analysis of systems; however, most of the analysis tools are focused towards the modeling of large and ultra-reliable systems. In addition, these software tools are not able to analyze systems that contain both electronic and mechanical components.

The goal of the work presented here has been to develop a dependability analysis software system to be used for the design and analysis of the electric wheelchair system. The software is targeted for the personal computer environment and allows the user to model the wheelchair at different levels of detail, from a system-level decomposition with the system broken into the main functional stages to the modeling of redundant components within the stages. As mentioned earlier, the software system is being designed to handle the electrical, mechanical, and electromechanical components in a single model.

MODELING FOR DEPENDABILITY ANALYSIS

To model any complex system for the purpose of dependability anaylsis, *structural decomposition* is first applied to reduce computational complexity. In structural decomposition the system is broken into smaller subsystems, and the reliability (and other measures of dependability) of the system is found as an aggregate of the subsystem reliabilities. Structural decomposition is valid as long as the subsystems are independent of each other in their failure and fault recovery mechanisms.

Inherent independence between stages in the wheelchair is used to make a structural decomposition at the highest level. For example, the wheelchair can be divided into an electrical and mechanical system, with the electrical system being further divided into different stages that are assumed to be in series, as far as reliability is concerned. Typical independent stages of the electrical system might include: (1) the user command sensors, (2) motor feedback sensors, (3) controller electronics, (4) motor drive electronics, and (5) the electric motors. The user can define more stages as the need arises, but all the stages at the highest level are assumed to be in series.

The second step is to model each of the stages defined during initial decomposition. Each stage can contain different component types, some of which may be redundant. For example, the electronic controller may contain two central processing units (CPUs), two memory boards, and one input/output (I/O) unit. The user also has the option to further decompose the stage, if possible, into substages that are independent in their failure and recovery mechanisms. The modeler will eventually, however, reach a situation where further structural decomposition is not possible. At this point, the modeler will describe the *behavior* of each component using markov models.

MODELING APPROACH

The approach to the modeling of an electric wheelchair system using the software system is outlined below. The software system is a collection of software routines, some of which have been developed locally and others of which are commercial products. The routines are currently being integrated so that use of any particular software routine is transparent to the designer.

Figure 1 is a graphical representation of the flow of the design process. It consists of four primary steps. The detail of each of these steps is outlined below:

Step I: The user determines whether or not the system can be structurally decomposed. The top-level decomposition is recorded using the software system. One possible decomposition is: controller, battery, motor, joystick, tires, and frame.

Step II: For each top-level components, the designer must construct a model. Further structural decomposition of any component is first performed if possible. Models can be assigned using either predefined models or user-specified markov models. Markov models are constructed by the user by allowing the various "states" or conditions in which the wheelchair can reside to be specified. These states are primarily determined by analyzing the particular component with regard to its failure modes. The modeling process supports state transitions for both the failure process and the repair process. The software currently contains eight predefined models and the ability to store additional user-defined models.

Step III: The user must specify the transition probabilities between the various states of each model using the failure rates, repair rate, or some variance of each. The software system has routines to support the calculation for both electronic and mechanical components. Routines have been included to support the estimation of the failure rates of integrated circuits, printed circuit boards and total electronic systems. Failure rate estimation for mechanical components are supported using finite element analysis routines to determine the load spectra. Fatigue analysis routines provide failure rate estimates using the load spectra information. In addition, the dependency of a transition probability within the model of one component on the state of another component can be modeled. The transition probability is modified based on the length of time the other component has been in a given state. For example, the deterioration over time of the chair's tires may be used to modify the failure rate of the drive motors.

Step IV: Estimates for the reliability, availability, and safety can be determined for either each of the components or the total system. Graphical output is also available.

The software system is designed to be used in an iterative mode. Once dependability estimates are determined for a given configuration, changes can be made to the transition probabilities, to the models, or to the overall structural decomposition. Additional features are also available within the software system for the creation of library models from component descriptions and system descriptions.

CONCLUSIONS

The system described in this paper is a highly-interactive software package to support analysis during the design and evaluation of electric wheelchairs. The development has progressed to the point where future efforts will focus on further refining the software and performing extensive evaluations of new and existing electric wheelchair designs.

ACKNOWLEDGEMENTS

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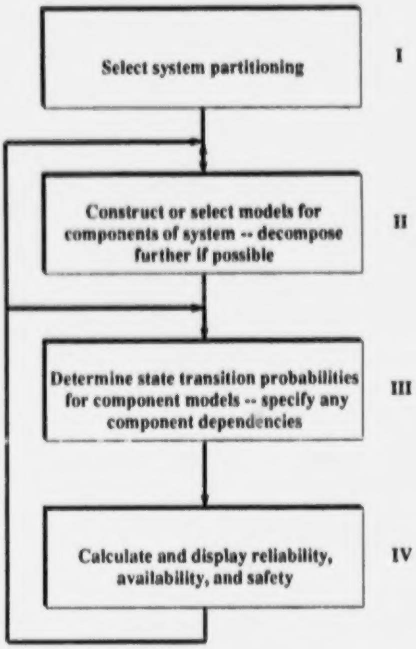
Select system partitioning
I
Construct or select models for components of system -- decompose further if possible
II
Determine state transition probabilities for component models -- specify any component dependencies
III
Calculate and display reliability, availability, and safety
IV

Figure 1. Dependability Analysis Process Flow

Development of a High Reliability, High Efficiency Curvilinear Synchronous Wheelchair Drive System

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VA Medical Center, Atlanta, GA

Abstract: The Veterans Administration Rehabilitation Research and Development Center in Atlanta has been developing a new motor system for use in powered wheelchairs. The system was designed for reliability, efficiency and improved control. The motor system makes use of advanced materials and electronics which allow great flexibility.

In the early 1980s, the Atlanta Veterans Administration Rehabilitation Research and Development Center (Rehab R&D) began studying the needs and wants of power wheelchair users. The chief complaints among users were of low reliability and short battery life. Both of these problems result in loss of mobility, as users tend to restrict travel for fear of mechanical breakdown. Battery life places an absolute upper limit on the distance that may be travelled. In addition to the loss of mobility and independence, repairs and replacement batteries can place a severe economic strain on users who must pay those costs themselves. Atlanta Rehab R&D began research into wheelchair controllers in response to these needs (Kelly[1]).

Although the goal of improving battery life was partially met by improving the efficiency of the power electronics, the weaknesses inherent in the mechanical design of standard wheelchairs prevented any significant increase in efficiency or reliability. In standard power wheelchairs, torque is provided by high speed DC motors which are then geared down to a lower speed. The gearbox drives a small (3.5") pulley which provides power to the wheelchair wheel with a belt. The gearbox causes a loss of power due to bearing friction and added mass. The belt is the chief culprit in low reliability due to its tendency to slip when wet, under high torque conditions, or temperature extremes.

It soon became clear that a direct drive motor system was needed to eliminate the problems caused by the transmission. As no one else was doing research in this important area, Atlanta Rehab R&D received funding from the VA to develop a suitable motor.

Several electromagnetic machines were investigated, but the one found to be most suitable for direct-drive low-speed applications was the Permanent Magnet Synchronous Motor (PMSM). Most PMSMs are constructed in a cylindrical configuration, but the motor designed by Atlanta Rehab R&D is constructed as a disk. It is appropriate to think of the motor as a linear motor whose ends have been joined to form a circle, and it is thus called the Curvilinear Synchronous Motor (CSM).

Most electric motors are driven in a three phase fashion, but single phase motors have several advantages. They are lighter and more efficient due to shorter flux paths which allow thinner stator back irons. Shorter flux paths imply shorter windings and having less copper reduces flux losses and I^2R losses. The disadvantage of single phase motors is the inability to start when stopped at certain positions. The advantages of both types can be gained when the motor is constructed as three single-phase motors instead of one three-phase motor.

Building the motor in a compact disk form provides more torque due to a longer moment arm. It also allows it to be placed alongside the seat, next to the wheel. This frees room under the seat for other equipment such as batteries and respirators. It obviates the need for a transmission and the associated problems. The sealed disk configuration is not affected by temperature and weather.

The first CSM prototype had a diameter of 18". Following the trend toward smaller wheels on chairs, the second prototype has a diameter of 13". We expect the next prototype to be under 12". The 13" prototype rotor holds 50 wedge shaped high-energy magnets arranged radially outward. The magnets are held in place by a 'spider' shaped steel rotor (Figure 1). This is a double sided motor, so both sides of the magnets must be exposed.

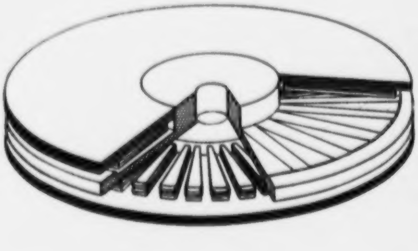

Figure 1.

The two stators 'sandwich' the rotor between them to double the torque provided by a single sided configuration. The layout of the stators is similar to the rotor, with 48 wedge shaped teeth made of soft iron. The teeth are wound eight to a half phase, with the winding direction alternating between teeth. This gives rise to a field wavelength *twice the slot spacing*. This means that a point on the rotor will see [360/(48/2)]= 15 complete electrical cycles in one physical revolution of the wheel. This very high resolution provides many opportunities for exacting control.

Because the motor was designed as a system from the ground up, we were presented with some unique opportunities to break with tradition. Although the Pulse Width Modulated (PWM) controller (Kelly[1]) was a vast improvement over conventional power stages, it is not the optimal solution for this application. One problem is inherent in any PWM system: electromagnetic interference (EMI) caused by the rapid switching of large currents. While we were concerned with the effects this might have on external devices such as medical equipment and instrumentation, our more immediate worry was the effect such EMI has on internal digital circuitry. Since we had planned to use a powerful microprocessor-based controller, we could not afford the problems this might cause. Another limitation of PWM is its obvious inability to produce a voltage higher than the supply voltage. The ability to do so is important to improve motor efficiency. Since power is the product of voltage and current, any combination of voltage and current producing the same product should be equally useful. This is not the case, however, since ohmic losses are related to the square of the current. This means that a doubling of voltage will result in a halving of the current, and a corresponding 75% reduction in ohmic losses.

We did not wish to break with the standard of using 24 volt batteries for power chairs, as these batteries have been well characterized. The solution was obviously some type of DC-DC converter, which does the job that a transformer does for AC. There are several DC-DC converter topologies, but all except the Cuk converter(Cuk[2,3]) exhibit the pulsed current characteristic of PWM. The Cuk converter offers a voltage gain of up to 3, which allows up to 72 volts to drive the motor. It also offers efficiencies as high as 88%. Since it has constant current on both input(low voltage) and output(high voltage), the problems with EMI are much less serious. In the Cuk converter, the duty cycle of the PWM switching waveform determines what part of the energy is stored in the capacitor and what part is stored in the inductor. Therefore, the current is not switched on and off as in other topologies. The Cuk circuit allows a very high power to volume ratio, making it much smaller than conventional converters. This again provides more space for other uses. Since the Cuk converter is so efficient, heat sinks may be very small.

As stated before, we took a systems approach to the entire motor. We designed our implementation of the Cuk converter with the expectation that it would be controlled directly by the system microprocessor. This is different from most chairs where the power applied to the wheels is merely an amplified version of the joystick signal. We envisioned a system in which the microprocessor would take the joystick information, process it according to preset and adaptive system specifications, and then command the power stage according to the results of the system processing. This will make the system more robust due to the smaller number of components subject to failure. In addition, the intelligent controller will be able to detect system faults such as a shorted joystick or overheating motor.

The controller will allow better handling, as variable ratio steering can be implemented in software. Greater safety can be achieved, for example, by limiting how sharp a turn may be made at high speed. A path memory will allow a user to back out of a tight space. The controller can continuously measure conditions such as motor temperature and battery capacity. The controller can alert the user as well as change its parameters to ameliorate the situation. For instance, as batteries weakened, the controller would alert the user as well as change to a lower speed/higher efficiency mode. Such changes would be subject to override by the user in cases of emergency.

One important feature for users and service providers is the ability to place limits on system parameters such as forward and backward acceleration, velocity, etc. This would prevent a child, for instance, from traveling at a dangerous and battery-consuming speed. The controller can also log usage and usage patterns to provide added feedback to service providers as well as users.

The controller can also provide less obvious benefits to the wheelchair system as a whole. Detection of system-threatening events such as motor overheating will increase reliability and decrease maintenance costs. Built in diagnostics will make troubleshooting simple and less expensive.

The controller is being implemented using the Texas Instruments TMS320C14 DSP microcontroller. This new processor features 6.4 MIPS performance and advanced features such as an event manager, single cycle multiply, and a barrel shifter.

ACKNOWLEDGEMENTS

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QUAD COMPARATOR CIRCUIT

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ABSTRACT

The Fortress Scientific Commander and the Everest & Jennings Omni-Pilot controls have other control modes besides driving the wheelchair. These modes are : driving, environmental control (Ultra 4) and tape recorder (Sony) while the Omni-Pilot has the additional mode of infrared transmission. A seldom used function on these controls is the tape recorder function. A quad comparator circuit was designed and developed to allow the tape recorder mode output to be used for other applications. The circuit plugs directly into the existing 1/8" jack on the Commander and Omni-Pilot and provides the equivalent of four single switch outputs.

INTRODUCTION

Proportional joystick interfaces supplied with powered wheel-chairs do not represent a viable mobility interfacing solution for severely physically involved individuals. A number of digital interfaces have been developed for the cerebral palsied population that use one to five switches to control wheelchair operation. Examples of digital interfaces are: the Microprocessor Scanning Interface (1) (2), Capacitive Touchplate Interface (3), Microswitch Joystick, Head Position Interface, and Thumb Control Interface (4). Most clients of the Interface Program at the Hugh MacMillan Medical Centre (H.M.M.C.) use "switch" type interfaces provided by the Program. All of these interfaces require utilization of either the Fortress Scientific Commander or Everest & Jennings Omni-Pilot controls. This paper describes the design and development of a quad comparator circuit that can be used in conjunction with these controls to access other devices in addition to the wheelchair. It is essential for many clients to be able to operate devices such as powered recliners, personal computers and augmentative communication controls. Possible applications of the quad comparator circuit are shown in Figure 1.

HARDWARE DESIGN CRITERIA

The design criteria of the quad comparator circuit are summarized below:

1) The circuitry should use the supply voltage from the Commander or Omni-Pilot.

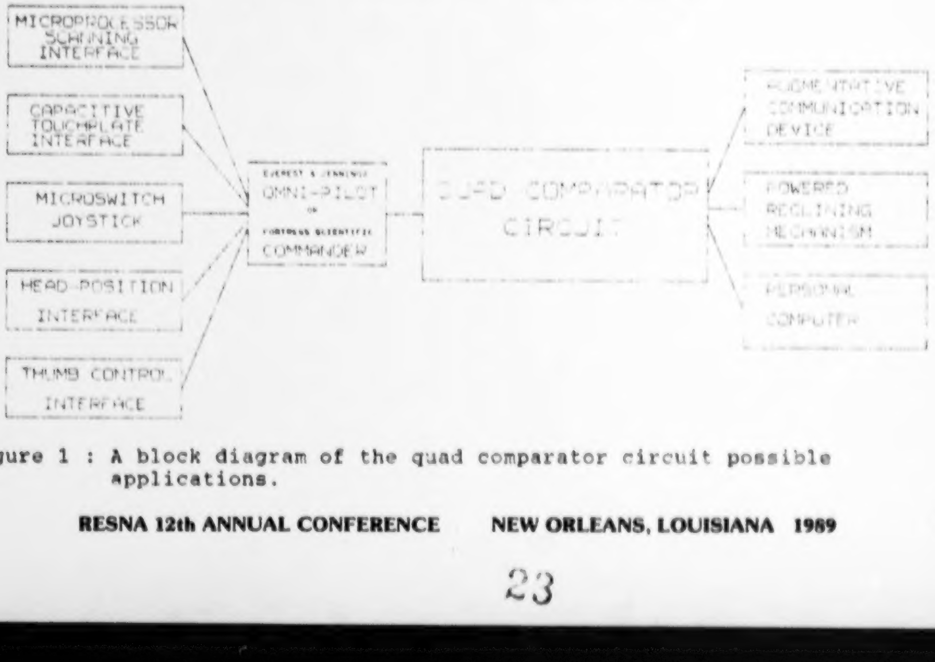
MICROPROCESSOR SCANNING INTERFACE
CAPACITIVE TOUCHPLATE INTERFACE
MICROSWITCH JOYSTICK
HEAD-POSITION INTERFACE
THUMB CONTROL INTERFACE
EVEREST & JENNINGS
OMNI-PILOT
OR
FORTRESS SCIENTIFIC
COMMANDER
QUAD COMPARATOR CIRCUIT
AUGMENTATIVE COMMUNICATION DEVICE
POWERED RECLINING MECHANISM
PERSONAL COMPUTER

Figure 1 : A block diagram of the quad comparator circuit possible applications.

2) Power consumption of the circuit should be minimized because of limited capabilities of the power source.
3) The circuit should be directly pluged into the existing 1/8" jack on the Commander or Omni-Pilot.
4) The four outputs should be compatible with electromechanical or electronic switches that can provide a contact closure to ground or an active logic "0".

CIRCUIT DESCRIPTION

A block diagram of the quad comparator circuit is shown in Figure 2.

Functions in the tape recorder mode, Play, Record, Fast Forward and Rewind, were accessed through the wheelchair driving interface and correspond to the Forward, Reverse, Left and Right interface switch activations. The Sony tape recorder, for which this mode was originally provided, is no longer in production. The H.M.M.C. quad comparator circuit was designed to plug directly into the existing 1/8" jack on the Commander and Omni-Pilot and provides the equivalent of four switch closures (active low).

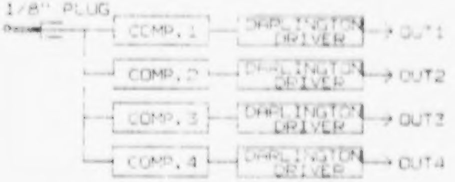

Figure 2 : A block diagram of the quad comparator circuit.

A low power, low offset voltage quad comparator integrated circuit was used in the design. COMP1 through COMP4 (Figure 2) convert low level analog signals corresponding to selected functions to high level digital outputs. The output signals drive high current Darlington drivers capable to sink up to 350 mA each, which is sufficient to operate relay coils. The circuit is powered by +5V supplied from Omni-Pilot or Commander.

CONCLUSIONS

A number of Quad Comparator circuits have been built and supplied to our clients. Most of the devices drive powered reclining mechanisms while others operate microcomputer based communication devices such as a Light Talker or MOD-keyboard.

ACKNOWLEDGEMENTS

We would like to acknowledge the Metropolitan Toronto Police Association for their support of the Interface Program and its work.

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ADDRESS FOR CORRESPONDENCE

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SEMI-LATCHED MODE SINGLE SWITCH WHEELCHAIR INTERFACE

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ABSTRACT

A microprocessor-based scanning interface has been developed for the disabled who can only operate one single ability switch. A semi-latched mode of directional control is implemented. It is suitable for users who can only operate a switch intermittently. This paper describes how this mode of control is different from the traditional non-latched mode and the inherently unsafe latched-mode.

INTRODUCTION

For individuals who lack the dexterity to operate a proportional joystick to control a powered wheelchair, a multi-switch unit or a single switch may be used for non-proportional directional control. The non-latched method of control is normally used. That is, the user activates a switch to start his wheelchair in a given direction and releases the switch to stop it. For users who only has the ability to activate one switch intermittently, a latched-mode of control is possible. In this mode, the user activates a switch once to start the wheelchair and a second time to stop it. It is dangereous in the situation when the wheelchair is moving and the user becomes unable to operate the switch. In this case, the wheelchair stops only when the battery runs out. To overcome this inherent danger another mode of control is necessary.

METHOD

The scanning interface is shown in Figure 1. It has four directional arrows and a center CONTINUE position. The algorithm for the semi-latched mode of control is shown in Figure 2. The user activates his switch once to start his wheelchair and a second time to stop it. If the switch is not activated a second time after a preset length of time, the interface stops the wheelchair and issues a CONTINUE request. The wheelchair will continue to move in the direction it has been traveling if the

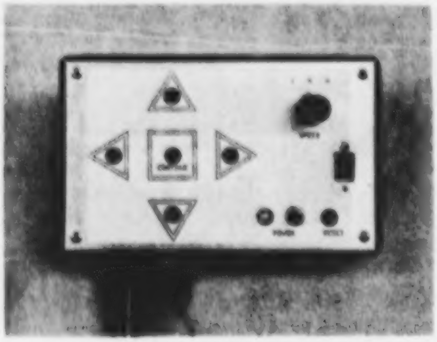

FIGURE 1: SINGLE SWITCH WHEELCHAIR INTERFACE

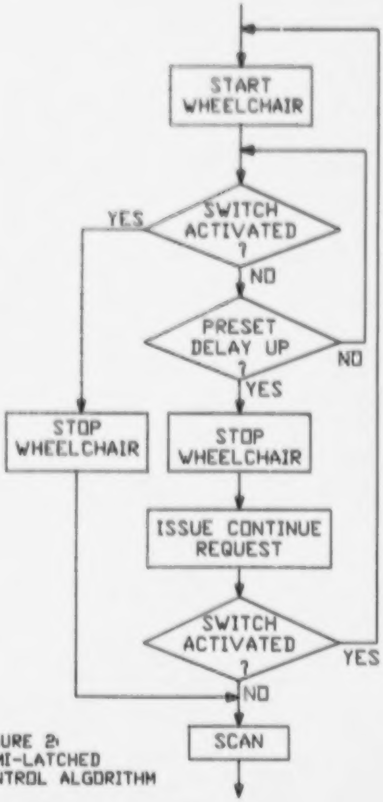

FIGURE 2: SEMI-LATCHED CONTROL ALGORITHM

user responds to the request by activating his switch. The interface will scan to the next directional position if the user ignores the request.

To free the user from having to look at the scan lights, each scan position is announced by a single character morse code. The characters are Forward, Right, Backward, Left, and Continue.

In order to make the interface useful without customization for a wide range of single switch users, a number of features are selected by switches accessible on or from the front panel.

Three wheelchair speeds are selectable by a rotary switch on the front panel. Since control rather than speed is preferred, the slowest speed is adjusted to coincide with that of a given wheelchair.

DIP switches accessible from the front panel select a number of operating parameters. Four scan speeds are available. Morse code speeds are related to scan speeds. One of the four speeds is an extra slow one for learning. The semi-latched mode or the non-latched mode of control can be selected. In the semi-latched mode, two preset lengths of time before issue of a CONTINUE request are available. For users with a hearing disability or who prefer to look at the display, the Morse code announcement can be disabled. This will also has the effect of speeding up the scan rate by saving the time it takes to sound the Morse code.

If the interface does not detect a switch activation after five scan cycles, scanning stops and it goes into standby. Once a switch activation is detected, scanning resumes, starting from the forward position.

A 6802 microprocessor is used as the controller. A bridge circuit is incorporated so that the interface can directly replace a proportional joystick such as that from Fortress.

Discussion

An eight-bit microprocessor is used for the interface. If the interface is only used for wheelchair control, an eight-bit micro-computer such as the 68705P3 will be more appropriate because of the lower cost and smaller package size. The interface is designed to directly replace a proportional joystick to save the cost of a digital controller.

Work is underway to add two features to the interface in standby. Firstly, a lifter interface will raise the motor drive for power add-ons with a motorized lifter. Secondly, a communication interface will enable the user to operate environmental controls.

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VECTORPLANE; AN APPROACH TO CONTOURING POWERED MOBILITY CONTROL

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ABSTRACT

This paper presents a wheelchair control algorithm utilizing a lookup table. This process allows great flexibility in configuring powered mobility to the abilities and needs of individual users.

BACKGROUND

Until recently, analog control systems were used in powered mobility systems. Typically these systems incorporated therapist settable controls to limit acceleration and speed of direction and turns. Some manufacturers are now marketing control systems using digital microprocessors. Use of microprocessors allows one unit to be used for many input devices such as proportional and microswitch controls. Beyond the input control flexibility allowed by the use of microprocessors, input-output transfer characteristics could be modified for each user.

INTRODUCTION

The technique presented here, "VectorPlane" uses a computer lookup table to modify the drive motor response to proportional control input.

Although lookup tables are linear within the computer, it is best to conceptualize this table as two dimensional. As shown in figure 1, the X and Y control outputs are used to address a lookup table. Each addressed memory location has X and Y vector information entered by the therapist or rehabilitation technologist. By allowing each combination of X and Y input to have an individual X and Y provides countless contouring possibilities.

For Example:

(1) Reducing the turning response at high forward or reverse speeds.

(2) Implementing reversed or turned joysticks such as chin and head controls. Presently this can entail rewiring the control and / or motors, while here the proper XY vector could be entered.

(3) Compensating for reduced range of motion either along one axis or area of controller movement.

The degree of contouring available depends somewhat on lookup table memory size. For example, first implementations will use the four most significant bits from each of the X and Y input control analog to digital conversions. This creates a 256 byte, 16 X 16 matrix of possible vectors. The eight bits of data resulting from the lookup process contains four bits for each axis. Applying the 2^4 or 16 possible values between left, right, forward, reverse, and a deadband area, leaves seven possible steps for each direction. Instead of simply truncating the control input data at four bits, the least significant four bits of each axis are used in a two dimensional interpolation process.

As a physical analogy for the interpolation process, suppose there is a square wheat field with weathervanes at each corner measuring windspeed and direction. By inspection, for the center point of the wheatfield, windspeed and direction could be estimated by averaging the four north/south windspeeds and the four east/west windspeeds. Estimating windspeed and direction at places other than the corners is more involved, requiring interpolation along both axes.

If the resolution available from the 256 byte lookup table is insufficient for control contours such as exponentiation, more memory can be thrown into the fray. For example, both the X and Y conversions could be concecated to create a 16 bit address pointing to a 16 bit word of 8 bit X and 8 bit Y vector data. This would require two 64 Kilobyte memories, for a total of 1 megabit of storage. Of course the interpolation process could use any size lookup table between the extremes mentioned here.

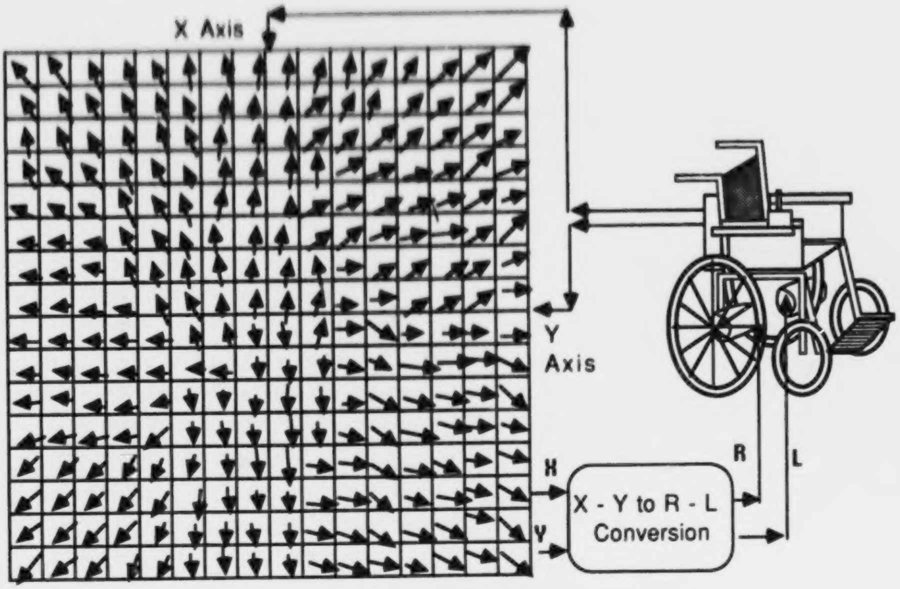

Figure 1, Block diagram of VectorPlane control process

One key consideration for using the VectorPlane approach will be the visual presentation and modification of the vectors. One possibility is use of a two button proportional joystick. Activating one button would translate joystick movement to move amongst the vectors, while depressing the second button allows speed and direction of individual vectors to be modified. This could be unweildly for the larger lookup tables and several preset contours could be available for further customization by the therapist or rehabilitation technologist.

SUMMARY

Using X and Y input data to address a lookup table allows a wide variety of transfer functions between control input and wheelchair response, allowing a better match between the mobility system and end user.

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3.1

IT'S ACADEMIC: COMPUTER ACCESSIBILITY ISSUES IN HIGHER EDUCATION

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INTRODUCTION

Academic institutions are among the largest contemporary consumers of computers. Although the general literature on accessibility may be useful, there are some factors specific to accessibility in higher education that are just beginning to be addressed. Among these factors are: responsibility and funding, facilities, training, planning, and the ways in which computers are used on campuses.

GENERAL ISSUES IN CAMPUS ACCESSIBILITY

Responsibility and Funding

On a short-term basis, it may be necessary to appropriate special funds to acquire adaptive equipment. Input on equipment purchase should be solicited from disabled student service officers, the central organization overseeing computer use (if one exists), individual academic departments, and probable users of equipment. Eventually, funding and oversight for adaptive equipment implementation and maintenance should be built into the budget of a computing area.

Facilities

The most highly adapted computer is useless if a person with a disability has difficulty physically gaining access to it. In addition, the computer facilities with adaptive equipment will need to be open as many hours, if not more, than other facilities, to allow students with disabilities a proportionate amount of time to finish their work. Finally, although the adapted computers should be useable by non-disabled students, a clear policy should be established to allow those who need to use the special equipment to have priority in using adapted machines.

Training

Like other neophyte computer users, people with disabilities are likely to need assistance in their initial encounters with computers. Those supervising an area with adaptive equipment should be familiar with the operation and maintenance of adaptive software and hardware, or know who to contact for information. Those in other areas should know where equipment is located so that they can appropriately refer disabled users. Reference materials should be available in a variety of formats (e.g., audiocassette, electronic, Braille).

Planning

The makeup of the disabled population at any institution from year to year may be unpredictable. Because of this unpredictability, planning should encompass a wide range of the more common disabilities, and, if possible, provide funds on an on-demand basis to assist those with more unusual situations. Devices such as ComputAbility's Aid+Me, which allow a variety of different adaptive devices to be plugged into a computer with minimal adjustment, would accommodate non-standard input devices owned by either the facility or the user.

SPECIFIC ISSUES IN CAMPUS ACCESSIBILITY

Library Facilities

Automated information services available to the library users, such as the on-line catalog, are usually run from a mainframe computer to allow simultaneous access by large numbers of people. Since there is no adaptive equipment that can be used on a mainframe per se, these services should be compatible with a variety of microcomputer communication programs so that users requiring adaptive equipment may access the information via modem, either on their own microcomputers or on those located in the library. The possibility of testing off-the-shelf library automation packages with a variety of communication programs and adaptive software should be investigated before making a final purchase decision.

Mainframe Computers

Mainframe computer systems on campuses have a variety of uses, from running electronic bulletin boards and mail systems to providing programs required in coursework. Besides the mainframe access problems discussed above, the additional problem of computer accounts arises. Access to these mainframes is often based on signing in under a class-related or departmental account, to which "money" is allotted and used at a rate dependent on the amount and time of day of use. Factors related to use by people with disabilities (e.g., slower access if speech synthesis is used) may eat up the money in an account at an exorbitant rate. Therefore, some arrangement may need to be made to ensure that additional funds are available to users with disabilities in proportion to the amount of extra time they require beyond what a non-disabled user needs to accomplish the same on-line task.

Classwork

Professors may indicate that papers and reports should be handed in in word-processed format or on floppy disks. Students may also be required to generate computer graphics, use an interactive training software program, or run a statistics package. A college may mandate (or strongly suggest) that certain software be used, or even that a certain type of computer should be purchased. Whenever specific software or hardware is required by the professor or institution, a mechanism should be set up so that students who would have trouble using the equipment due to a disability can work out an alternate method of accomplishing the work.

Computerized Registration
Many campuses are turning towards "touch-tone registration," where students need only use a touch-tone phone to link into a mainframe computer and indicate what classes they wish to take. The registration program should be set up to be compatible with TDDs.

WORK IN PROGRESS

At least two groups are currently working on solving issues relating to computer accessibility on campuses. AHSSPPE, the professional organization of disabled student service office directors, has recently formed a special interest group on computers and disabled students. EDUCOM, a consortium of more than 500 institutions of higher education focused on effective use of computer technology, formed a project group in October of 1988 to address the issue of accessibility and produce a handbook on sources of information in the area of adaptive equipment. In addition, individual campuses--such as the University of Nebraska, Nassau Community College (New York), The University of Michigan-Ann Arbor, and California State University-Northridge--have been involved in setting up adaptive equipment centers, training programs, user groups, and other answers to the needs of disabled computer users.

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A MODEL FOR ALTERNATE ACCESS SYSTEMS

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ABSTRACT

This paper describes a model of an ideal alternate access system for the control of computer-based technology by individuals with disabilities. The model is a framework of modules which perform various translation functions. As a structural standard the model has practical implications for developers, practitioners, and users. An implementation would have three components: a *run-time system*; a *configuration facility*; and a *developer's toolkit*.

INTRODUCTION

Researchers at the University of Toronto and the Hugh MacMillan Medical Centre have proposed a generalized model for computer access systems. This proposal stems from a three-year Shared University Research project supported by IBM Corporation. It follows the principles outlined in the paper "Guidelines for Alternate Access System Developers" (McDougall, Knysh, Sainani, Shein, and Lee, 1988).

As a basis for determining what functions and features an ideal access system should have, the project team evaluated various commercially available access systems, including the MOD Keyboard System™, Adaptive Firmware Card™, and PC AID™. An analysis of translation processes between the user and the computer identified those functions which are common to all access systems.

The model also includes certain desirable features which current access systems lack. Some systems are not flexible enough; it is not possible to tailor their functions to individual users. None of the access systems tested can adapt the output from a computer to accommodate different users' sensory modes.

The team has developed a computer simulation of the model using the interpretive object-oriented programming language Smalltalk™. In this implementation, each access system function is a Smalltalk object. Information passes from one object to another throughout the translation process. Although it is too slow for use as an actual access system, the simulation demonstrates the integrity of the model. Implementing the model in a compiled rather than an interpreted language should speed the flow of information enough to make the system usable.

MODEL

The proposed model translates information between a user and a target system through a framework of modules. Each module fits into the framework to perform one of the functions required for access. Developers can create new modules to meet particular needs and to keep pace with advances in technology. The pool of available modules serves as a kit from which practitioners can assemble custom alternate access systems for individual users. This model resembles the user interface management systems discussed in current computer science. An implementation of the model would have three components:

(1) a "run-time" system with a managerial core to which modules are added, forming a complete alternate access system

(2) a configuration facility that enables the user or a helper to configure the run-time system

(3) a developer's toolkit for creating new modules

Run-time system

A particular user's run-time system includes modules implementing the functions which that user requires for access. There is also a core operating system which manages all communication among modules. Parameters define each module's operation. The modules link together in a framework as in Figure 1.

The following functions comprise a complete run-time system:

❑ *Input devices:* physical apparatus, such as keyboards and switches, which the user manipulates to produce input

❑ *Input translation:* converts raw data from input devices into signals understood by the rest of the access system; translators are also known as *device drivers*

❑ *Input filter:* eliminates or reduces undesired input

❑ *Selection techniques:* methods by which the user selects items of information for input to the target system

❑ *Input mapping:* matches selected items to data understood by the target system

❑ *Translation to target input:* passes input information to the target system

❑ *Translation from target output:* receives output information from the target system

❑ *Feedback mapping:* renders feedback from the target system into a form comprehensible to the user

❑ *Feedback combination:* merges feedback from the target and access systems

❑ *Output translation:* converts the combined feedback from the target and access systems to signals for output devices

❑ *Output devices:* present feedback to the user

❑ *Operation assistant:* controls the parameters of the access system during its operation and allows the user to alter them

Configuration Facility

The configuration facility enables a user or practitioner to assemble a customized access system. Assembly involves selecting modules to perform the required access functions and setting their parameters for optimal performance.

A configuration facility would permit the selection of whatever input device best suits a user's needs. It would provide an assortment of input filters such as low-pass and key acceptance delay.

The facility would supply predefined selection techniques, selection sets, and mapping sets to choose among. Available selection techniques might include automatic scanning, inverse scanning, step scanning, directed scanning (such as with a joystick), direct selection (such as with a touch screen), single-switch Morse code, and double-switch Morse code. Selection sets might contain characters, numbers, words, and operations. Mapping sets would be available for popular target applications. The configuration facility should also allow easy creation and editing of new selection and mapping sets.

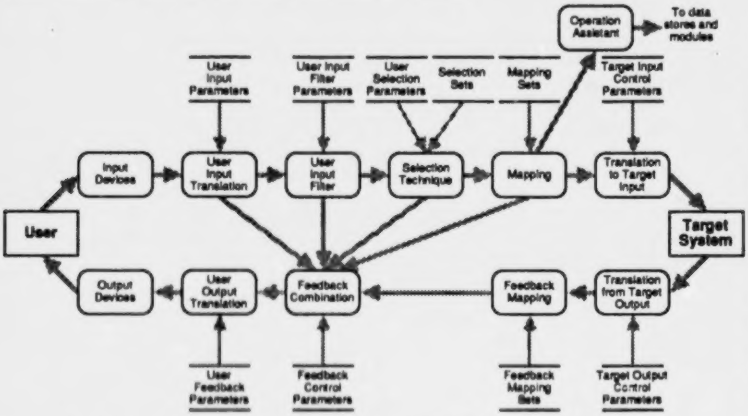
Operation Assistant
To data stores and modules
User Input Parameters
User Input Filter Parameters
User Selection Parameters
Selection Sets
Mapping Sets
Target Input Control Parameters
User
Input Devices
User Input Translation
User Input Filter
Selection Technique
Mapping
Translation to Target Input
Target System
Output Devices
User Output Translation
Feedback Combination
Feedback Mapping
Translation from Target Output
User Feedback Parameters
Feedback Control Parameters
Feedback Mapping Sets
Target Output Control Parameters

***Figure 1:** Suggested framework for a run-time core of an alternate access system.*

Software and hardware interfaces for a variety of target systems would be available. It would be possible to choose one or more target systems for an access system to support. Like the input modules, the various output translation modules would be easy to select and configure.

The wide range of combinations of features makes configuring the access system a complex task. An expert system may be able to guide the design of an access system by ensuring that module choices and parameter settings are logical and consistent (Shein, 1988).

Developer's toolkit

The developer's toolkit is a set of resources for a programmer to use in creating a new module, such as a new device driver or scanning technique. By using the toolkit, the programmer could design the new module to be compatible with the overall access system framework. The programmer could then add the new module to the existing system without having to redesign the entire system in order to support it.

Modules in the access system implement an inventory of standard functions which meet currently established requirements of alternate access. The framework which the modules fit into is also standard and unchanging. It defines ordering relationships among the modules as well as protocols for communication. The developer's toolkit would include rules for module functions and relations. By following the rules laid out in the toolkit, therefore, a programmer could design new modules to replace the old without affecting the operation of the rest of the alternate access system. The implementations of the standard functions would thereby remain contemporary, reflecting improvements in access methodology. It would also be possible to create modules which added new functions to the standard inventory, as long as they conformed to the framework protocols.

The toolkit would incorporate a development facility befitting the implementation of the access system model. Modules in the system may be native-code processes in a multitasking environment, for example, or objects in an object-oriented environment. The toolkit might incorporate a compiler for the former or specialized classes for the latter. A suitable library facility would store the available modules so they could be selected for use as needed.

The research team has encouraged other developers to consider the proposed model in their designs of access systems. Adopting a common framework would allow developers to focus their expertise on individual modules without having to create entire access systems to support them.

ACKNOWLEDGEMENTS

The team thanks IBM Corporation for supporting their work. From July 1985 to June 1988, IBM funded a Shared Universities Research Project linking the Hugh MacMillan Medical Centre and the Department of Rehabilitation Medicine at the University of Toronto. Many members of the Rehabilitation Engineering Department and the Augmentative Communication Service at the Hugh MacMillan Medical Centre also deserve thanks for their helpful insights and assistance.

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GUIDELINES FOR ALTERNATE ACCESS SYSTEM DEVELOPERS

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ABSTRACT

This paper proposes twenty-two design guidelines for developers of alternate access systems. The guidelines cover five areas: *Input, Output, Selection Techniques, Setup and Configuration, and Target System Connection*. By following these guidelines, developers should be able to provide access to computer technology for a wide range of users.

INTRODUCTION

During a three-year Shared University Research Project supported by IBM Corporation, researchers at the University of Toronto and the Hugh MacMillan Medical Centre reviewed a wide variety of computer access techniques. The team consolidated related clinical and technical knowledge in a set of guidelines (McDougall, Knysh, Sainani, Shein and Lee, 1988) to assist developers in the design of future alternate access systems for computer-based technology.

The term *access system* refers to the hardware and software components that enable a person to interact with a computer, and the methods and processes involved in the interaction. It is distinct from the *target system*, the computer-based technology to which the user has access. An *alternate access system* incorporates components other than the standard configuration typically used with a computer.

GUIDELINES

The twenty-two proposed guidelines are listed below under the following headings: Input, Output, Selection Techniques, Setup and Configuration, and Target System Connection. Depending on the nature of an alternate access system, some or all of these guidelines may apply to its design and development.

It is important to note that the guidelines are intended as guiding principles—they are not to be interpreted as rules or standards.

Input

Input guidelines deal with handling the raw data which the user supplies. This involves capturing, translating, and filtering the information so that other components of the alternate access system can process it and send it to the target system.

☐ *Support a wide range of input devices:* Access systems should include the necessary external connectors and should be able to interpret the data that devices transmit.

☐ *Support future input devices:* Since it is impossible to predict exactly how future devices will work, the design of an access system should follow the concept of device independence. This approach matches real input devices with logical devices.

A logical device is an abstraction defined in terms of a type of input data. For example, logical devices can supply numeric values, strings of text, or locations in two or more dimensions. A device-independent access system translates data from physical input devices into this logical form, so that the core of the system does not depend on the nature of the actual devices.

☐ *Allow input device combinations:* Combinations of input devices may be more appropriate than a single device.

☐ *Support multiple input streams:* Access systems should accept input from more than one source at a time. Alternate input should not interfere with the standard source.

☐ *Provide input filters:* Control problems resulting from tremor, poor targeting, or poor operating conditions can produce unintentional input. Various programmable input filters could reduce or remove these errors.

Output

Output guidelines cover the presentation of information to the user. In addition to the target system, each component of the access system may generate feedback which must be conveyed to the user in a comprehensible form.

☐ *Support a wide range of output devices:* Access systems should provide external connectors for a variety of output devices and should be able to supply information in whatever form these devices require.

☐ *Support future output devices:* The concept of device independent design (Fels, 1987) again applies. Output information should be structured in such a way that its meaning is independent of the details of its presentation.

Ideally, a target system should supply information in a modality-independent format so that an access system can represent it in whatever sensory mode (visual, auditory, or tactile) is most suitable for the user.

☐ *Allow output device combinations:* An access system should be able to send output to multiple devices and divide feedback among different devices and presentation modes.

Selection Techniques

These guidelines deal with the way in which the user selects items of information for input to the target system.

☐ *Support a full range of selection techniques:* Access systems should provide a framework in which many different selection techniques can function. There are four general approaches to selection that are typically used: direct selection, scanning, directed scanning, and encoding (Vanderheiden and Lloyd, 1986).

☐ *Support flexible selection sets:* The framework should allow various arrangements. Selection sets can be organized in a matrix or a QWERTY keyboard layout, for example, as a single page or one of multiple pages in a hierarchy or network structure.

It should also be possible for selection sets to contain operations as well as text and images. Typical operations include choosing the desired target system, starting an application program, issuing commands, moving among selection set pages, and setting access system parameters to a particular user's abilities.

☐ *Provide facilities for selection set customization:* The user should be able to create and edit new selection items and sets. A library facility should store and retrieve them for use.

☐ *Allow input mapping:* A selection set can represent the information that a target system requires according to whatever scheme or metaphor is most meaningful to the user. Individual selection items are mapped to data significant to the target system.

☐ *Allow input acceleration:* Various strategies can speed up input. Compansion methods such as abbreviation-expansion convert single or multiple selections into a larger quantity of information. Prediction techniques attempt to determine future selections from current ones and thereby save the user the trouble of making them.

Setup and Configuration

These guidelines cover the management of a flexible alternate access system. The parameters referred to below are numerical values which define the exact details of the functioning of the access system. Typical parameters are key repeat time, delay time, scanning rate, volume settings, and filtering levels.

Access system functions are processes that information undergoes within the system, such as input filtering. Access system modules are actual implementations of functions. For example, an averaging filter used with a joystick is a module implementing the filtering function. A configuration is an instance of an access system. It consists of a specific collection of access system modules with all parameter values defined.

☐ *Allow user control of access system parameter settings:* The user should be independently able to adjust the access system parameters.

☐ *Allow run-time control of parameter settings:* Conditions such as fatigue can affect the user's performance. Since these conditions vary during the operation of the access system, the parameters which compensate for them must be adjustable throughout.

☐ *Avoid ineffective configurations:* Access system parameters and functions are interdependent, and not all configurations are viable. Rules for configuration will ensure practical systems.

☐ *Support storage and retrieval of configurations:* A library facility for the parameter settings and module linkages which make up configurations will make customization easier.

☐ *Allow immediate user control:* A computer, even with an alternate access system, should be ready for use as soon as it is turned on. The access system should automatically load a user's custom configuration, and it should initially supply a default configuration.

☐ *Allow for future expansion:* The design of an access system should consist of a framework which defines the functions and allowable interactions of a number of replaceable modules. As long as they follow the same principles of alternate access, future modules can replace the old without disrupting the rest of the system.

Target System Connection

The last set of guidelines deals with passing information between the target system and the access system.

☐ *Provide appropriate target system connectors:* Access systems connect to their target systems either physically or logically. A secondary computer, for example, connects to a hardware port on the primary computer. The target system redirects its flow of information through the data port. An access system of this kind must provide a range of hardware connectors and data protocols for the ports of its intended target systems.

Some access systems are based in software and run within their target computers. Here connection occurs at a logical point: the access and target systems meet in the operating system of the host computer. In this case the access system must match the input and output conventions of its target operating systems.

☐ *Support multiple target systems:* Where feasible, an access system should be able to direct its output to different target systems, singly or at the same time. Thus an access system based in a dedicated computer could operate another computer, an environmental control device, or a robot assistant.

☐ *Ensure portability between target systems:* Access systems which physically attach to their target systems should be easy to transport and hook up.

ACKNOWLEDGEMENTS

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Many members of the Rehabilitation Engineering Department and the Augmentative Communication Service at the Hugh MacMillan Medical Centre also deserve thanks for their helpful insights and assistance.

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ACCESS TO GRAPHICAL COMPUTERS BY BLIND USERS: RESULTS OF A PLANNING WORKSHOP

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ABSTRACT

The advent of computers with graphically based screens and user interfaces has made use of these computers by blind individuals impossible or at least extremely difficult. The task of making these computers usable is an enormous one since it involves both the technical problem of working within these operating systems, and the human factors problem of creating new human interfaces for the blind individual--interfaces which will give them access to these graphic computers and the graphics-based documents they will support.

To address this problem a planning workshop on access to graphics was held in October, 1988. The workshop was sponsored by the Trace R&D Center along with American Foundation for the Blind, the National Federation for the Blind, Smith-Kettlewell Institute for the Visual Sciences, and the Veterans Administration Blind Rehabilitation Centers. The workshop funded by the Veterans Administration, the Ameritech Foundation, and National Institute on Disability and Rehabilitation Research (NIDRR).

Results of the conference include pre- and post-workshop papers on this topic, cooperative efforts, and a listing of research priorities and research funding sources.

INTRODUCTION

Recent advances in computer display technologies are creating major barriers for blind persons. Although there are over 35 different aids and techniques available for providing access to the current generation of character-based screen displays, and several aids that can provide access to the newer graphic-based screens for users with low vision, there were no aids or techniques for providing full access for blind individuals to the newer computer systems, their operating systems, and the graphics based documents (figures, charts, etc.) created on them.

One immediate concern is the unavailability of screen image in a form that can be easily accessed and interpreted by special Braille, voice, or tactile display systems. While it was possible previously for special aids to access sections of memory and directly read the text that was printed on the screen, modern systems only maintain a bit image representation of the visual screen image. Furthermore, even if the text on the screen were provided (or reconstructed using optical character recognition), the full information content of the screen may not be discernible, since a significant portion of the information on the screen may be presented a) through the text's formatting, arrangement and location with respect to graphical elements, or b) directly in pictorial or graphic form. This problem is compounded by the fact that some of the major new operating systems by Apple, Microsoft, and IBM use overlapping images. This makes interpretation by external devices extremely difficult if not impossible without some cooperation from the computer and operating system composing the image.

In addition to the difficulties in getting access to the screen image, there are no good strategies for presenting the image to a blind individual. Better techniques are needed for handling the diverse formatting of text (style, font, size, and spatial arrangement) if these new screens are to be properly interpreted. In addition, there is a need to identify and develop specific strategies for allowing blind individuals to directly explore charts, diagrams, and other business and program graphics that are being used at a rapidly increasing rate in standard business reports and software.

One long term concern is the lack of good understanding of the current and potential perceptualization and conceptualization skills of the blind individual, and strategies for presenting information (not just the image) to these individuals in a way that is best matched with their skills. While much attention is being paid in industry to developing an "ideal" user interface (taking advantage of high quality displays) to allow sighted individuals access to screen information, little is understood about the "ideal" user interfaces for blind individuals to access the same information.

Another long term concern is that of designing computers to allow direct access to information from a computer (rather than from the screen image). If this could be accomplished, there would be no need for a smart interpretation device to translate the image to the intended information--a difficult task. Once the information is obtained from the computer, it could then be presented to blind individuals using their "ideal" user interfaces.

THE PLANNING CONFERENCE

Based upon these four concerns, six questions were addressed at the planning workshop:

1) What are the current and potential perceptualization and conceptualization skills of blind individuals, both for the congenitally blind and for those with acquired blindness?

2) What are the strategies for the presentation of information to blind individuals?

3) What are the types of information that the computer usually presents on the visual display?

4) How can this information be obtained from the computer?

5) Given the above information and the course of computer developments, what are the long term strategies for providing access to computers?

6) What are short term strategies for providing access to computers?

Key researchers, developers, manufacturers, and consumers working in this area were identified, with the assistance of an advisory team, and were gathered together for the workshop. On the advisory team for this process were Elliot Schreier, American Foundation for the Blind; Tim Cranmer, National Federation of the Blind; John Brabyn, Smith-Kettlewell Institute; Gregory Goodrich, Western VA Blind Rehabilitation Center; Harvey Lauer, Central VA Blind Rehabilitation Center; and William DeLaune, Eastern VA Blind Rehabilitation Center. Tim Cranmer and Harvey Lauer are individuals with blindness.

The workshop itself involved 37 participants. The size was kept as small as possible in order to maximize its effectiveness. There were eleven consumers, and representatives from seven manufacturers (IBM, AT&T, Microsoft, Raised Dot Computing, Telesensory Systems, Inc., Berkeley Systems Design, and Blazie Engineering). There were also thirteen researchers from the United States, one from England, and two from Sweden, and one from Spain in attendance.

In order that the entire meeting would not be spent bringing all of the attenders up to speed on recent findings and knowledge of the different members, pre-workshop papers by the participants were collected sent to all participants prior to the actual workshop. Some of the titles of the papers included:

Visual-Spatial concept Training as a Prerequisite for Comprehending Computer Graphics with 3-D Content
Cracking the Mac for the Blind
Computer Access: The National Federation of the Blind Approach
An Information Processing Model of Human-Computer Interaction for People with Blindness and Severe Visual Impairments
Communication Media for the Visually Impaired: Why One Medium Isn't Enough
The Functional Module Operating System: Isolating the Human Interface
Ergonomic Considerations and the Visually Impaired Computer User
Access to Graphic Environments
A Multi-Sensory, Nonvisual Interface to Computers for Blind Users
Perceptual and Conceptual Skills Under Visual Handicap: Perceptual and Task Factors in Understanding Braille and Tactual Graphs
Non-Visual Human Computer Interaction
Drawings as Representational Systems: Comparison Between the Congenitally Blind and the Sighted.

The planning workshop itself was organized around the six basic questions listed above. At the end of the workshop, individuals were identified and commissioned to provide post-workshop papers summarizing some of the discussions and conclusions made during the workshop. The summary papers are currently being collected and formed into a post-workshop document that will be given to all attenders, and will also be made available to others who are interested, through the Trace Reprint Services and possibly through a publisher. A sample list of the titles of the post-workshop paper include:

A View of the Macintosh and OS/2 in Tactile Terms
Overview of the Macintosh in Technical Terms with Hook Identification
Overview of the OS/2 in Technical Terms with Hook Identification
The Best Features of Screen Reading and Dedicated Programs for the Blind
Future Architectures
A Potpourri of Computer Access Approaches for Blind Users
Importance of Task and Training to Access Performance
Overview of Different Tactile and Haptic Displays
Use of Sound in Access Techniques
Use of Speech in Access Techniques
Guidelines in the Development of Electronic Documentation
Bibliography in Computer Access by Blind

The Trace Center will be using the post-workshop papers as a planning tool for its own efforts in this area. Also, both researchers and manufacturers have expressed an interest in this Planning Workshop and the resulting papers to assist them in their planning process, particularly with regard to identifying common access strategies and coordinating research.

Finally, any solutions to this problem will have to come from cooperative efforts between the computer manufacturers and the rehabilitation field. The participation and interest of computer manufacturers such as IBM, AT&T and Microsoft is a good sign that this type of cooperation is possible and in fact has already begun to take shape.

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ACCESS TO MICROSOFT WINDOWS 2.0 FOR USERS WITH PHYSICAL DISABILITIES

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ABSTRACT

There exist many software solutions for providing access to PC-DOS and MS-DOS computers for people with physical impairments. There are access programs that provide features such as StickeyKeys (for individuals who type with one finger, a headstick, or a mouthstick), SlowKeys (for individuals who tend to accidently hit keys), Typematic Rate Adjustment (for individuals who are slower at releasing keys), MouseKeys (for individuals who cannot use the mouse) and an Emulating Interface (for individuals who cannot use the keyboard at all but can use a communication aid that has a serial port).

However, none of these existing software solutions work with Microsoft Windows.

A solution has been developed by the Trace R&D Center to provide these features for Microsoft Windows 2.0. This was accomplished by rewriting the keyboard and mouse device drivers, and writing a Windows application program.

INTRODUCTION

Software solutions for providing computer access to people with physical impairments for computers running PC-DOS or MS-DOS rely on being able to Terminate and Stay Resident (TSR) and being able to hook into the keyboard, mouse, serial port, timer, and/or other software and hardware interrupts.

However, Microsoft Windows does not leave these TSR's operating. Windows takes over many of the software and hardware interrupts and replaces them with its own. Windows reinstalls the original interrupts only when quitting out of Windows or when running a non-Windows application from within Windows. Therefore, the special access software TSR's do not work under Windows when running Windows applications.

RESULTS

In order to provide the transparency at the application and the kernel level, it was necessary to work below the kernel level.

Below the kernel level, different members of the Windows family (e.g. Windows 2.0, Windows 286 and Windows 386) are different and so a choice had to be made as to which one to use. The Trace R&D Center felt it needed to demonstrate the feasibility of implementing these different features and not worry about implementing all these features on all the Windows families. Therefore, the Trace R&D Center chose to work with Windows 2.0 since it would work on all varieties of machines (8088, 8086, 80286, and 80386).

As mentioned in the introduction, some of the interrupts, such as the keyboard, mouse, serial port, and timer, are either re-initialized by the Windows kernel, or by the keyboard, mouse, and serial port drivers. Thus, in order to permit these access features to work under Windows, the keyboard and mouse device drivers needed to be rewritten to allow implementation of the special access features.

A working version of a set of revised keyboard and Microsoft mouse device drivers for Windows 2.0 has been completed. The new keyboard device drivers implement StickeyKeys, SlowKeys, and Typematic Rate adjustment. The mouse device driver was rewritten to allow programs to inject mouse actions. The keyboard device driver, in conjunction with the mouse device driver, implements MouseKeys. The keyboard device driver was also rewritten to allow injection of keyboard actions at a level that was not affected by StickeyKeys, SlowKeys or the Typematic Rate adjustment but could utilize MouseKeys. Both of these device drivers provide calls that let any program adjust many of the parameters involved in these features.

A regular Windows application program was also written to allow adjustment of the different parameters of these features. On all the features, the user can select whether the feature should be on when Windows is started, and whether feedback is desired when the feature is turned on or off. The user can select whether StickeyKeys should be turned off when two keys are held down, to give feedback on the state of the shift keys when pressed, or whether dual- or tri-state shift keys are wanted. The user can select the time before key acceptance for SlowKeys. They can select the time before typematic repeating and the repeat rate for the Typematic Rate adjustment. They can select the maximum speed and time to maximum speed for MouseKeys. Finally, the user can select the baud rate and serial port for the Emulating Interface.

This application program also lets the user save the different features' configurations to a disk file, and select which disk file configuration should be the default configuration upon start-up. It also lets the user easily change configurations by simply specifying a configurations file.

The device driver and program have proven to be transparent not only to Windows application programs, but also to the Windows kernel.

DISCUSSION

A number of attempts were made to implement these special access features using documented/standard Windows functions.

A potential solution which was investigated utilized the fact that Windows is message oriented. Application programs get their input from the user via a message queue. A program can simulate messages by using the Windows functions PostMessage or SendMessage.

However, these functions inject messages at a very high level in the message stream. This means that not only must one know the keystrokes or mouse activity one wants to simulate, but must also have some other high level information (information only the Windows Kernel can provide).

For instance, to inject keystrokes, one must know the handle to the Window (usually the window on top) that is expecting to get the keystroke message. One cannot just inject a keystroke and have the Windows kernel distribute it accordingly.

Likewise, for injecting mouse activity, the special access program must know exactly what is on the screen under the mouse cursor since mouse messages for movement or button presses vary depending on what the mouse cursor is over. For instance, moving the mouse cursor over a scroll bar sends a different message than moving it over a title bar.

Another potential solution, which was investigated for simulating keyboard activity, utilized the fact that Windows allows hooking into the keyboard message queue using the "SetWindowsHook" function. This function allows a program to look at the keystrokes coming through and either change a keystroke or inhibit it. However, it does not allow injecting multiple keystrokes per real keystroke, nor does it allow injecting keystrokes when there were no real keystrokes. Both of these capabilities are needed in order to implement StickeyKeys and the Emulating Interface.

For simulating mouse input, there is a call "SetCursorPos" in Windows to set the mouse cursor position on the screen. This allows a program to move the mouse cursor around. However, there is still no way to simulate mouse button presses once the cursor is moved to the position.

Finally, a major complication is that rebooting the computer is done at the device driver level of Windows. Therefore, injection of keystrokes in any of the previous ways mentioned above would not work to reboot the computer.

Therefore, since none of the regular Windows functions were able to provide the necessary transparent simulation of keyboard and mouse input, the Trace R&D Center began to look at non-standard ways to provide these functions.

In looking at the problem, it was determined that the only way to provide true transparent simulation of the keyboard and mouse input was to rewrite the device drivers of the keyboard and mouse to allow injection of keyboard and mouse activity into the device driver.

Since rebooting of the keyboard occurred at the device driver level, the keyboard-specific access features such as StickeyKeys, SlowKeys, and Typematic Rate adjustment had to occur in the keyboard device driver at a point earlier than the point in the keyboard device driver where the decision about rebooting took place.

A drawback to this approach is that it only works with those keyboards which are compatible with the IBM keyboard, and with mice which are compatible with the Microsoft mice (e.g. bus, serial, PS/2).

FUTURE

The Trace R&D Center is currently working with Microsoft to see how many of these features which have been implemented can be implemented on all their Windows products (Windows 2.0, Windows 286, and Windows 386) as standard features.

The Trace R&D Center is also working on hardware versions of the Emulating Interface for the Apple Desktop Bus (ADB) and the IBM PS/2 so that a communication aid that is set up to work with the Emulating Interface can also work with any computer which uses the ADB or an IBM PS/2. An ADB version will be ready by June 1989.

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COGNITIVE FACTORS AFFECTING ACCESSIBILITY OF COMPUTERS AND ELECTRONIC DEVICES

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ABSTRACT

Barriers to computer accessibility are presented not only by physical and sensory components of computer systems, but by their cognitive as well. This paper summarizes recommendations from clinical and educational literature for potential ways to reduce cognitive load in the design of computer systems, including input/interface control, presentation format, informational content and prompting. These recommendations should be interpreted according to relative priorities of flexibility and ease of use for a given user or set of tasks.

INTRODUCTION

Computer access involves not only the operation of input and output devices, but also the ability to use the computer system to accomplish a task. Many persons who have physical and sensory skills within normal limits are unable to access and use computers and other electronic systems because of the additional cognitive load introduced by the computerized presentation of a task. For instance, some early reading recognition programs for cognitively disabled persons were inaccessible to their target audience because the input mechanism (the keyboard) required a higher cognitive level than the task presented in the software. The design of computer systems for any category of user must consider the cognitive load of different system features, as well as the physical and sensory factors, which may interfere with accessibility. It should be noted, however, that user success or failure with different systems does not provide enough information to change design features, since it is difficult to determine whether the problems are due to difficulties of computer access, or to poor program design. A well-designed program can be made inaccessible to users by inappropriate input techniques, display characteristics, information content, or prompting, but a poor program will not be effective even if all program tasks are accessible to the user.

Because cognitive load varies greatly between different tasks and users, most guidelines for reducing cognitive barriers to computer use are very general. Recommendations from the most recent draft of design considerations from the Industry/Government Cooperative Initiative on Computer Accessibility (1988) include:

- simplify language in task instructions,
- provide on-line help,
- make displays simple, and
- provide consistent displays, menus, and selection techniques.

Implementation of these considerations in this form is difficult because the determination of what is simple or conceptually beneficial is largely subjective and difficult to measure across situations or users.

A more detailed list of recommendations for improving computer accessibility for persons with cognitive disabilities has been collected from rehabilitation and educational literature (see references for representative citations). The collected recommendations for designing software and hardware are given below, and divided into categories of 1) input/interface control, 2) presentation format, and 3) informational content/prompting. Since the recommendations listed are derived primarily from theoretical or clinical applications rather than experimental modification, some suggestions apparently conflict. For instance, voice output is used as a simpler means to present verbal information, yet such transitory signals increase cognitive load. Further integration of research from clinical and human factors studies is in progress, to quantify relative cognitive load of computer features and balance cognitive requirements of a task with characteristics of the user or task. The current recommendations are best used as factors to consider in attempts to optimize both flexibility and simplicity in hardware and software design.

INPUT/INTERFACE CONTROL

- Decrease visual and procedural complexity of control techniques. Recommended input techniques for low cognitive load include: touch window, light pen, touch pad, programmable membrane keyboard (often with picture cues), voice activation. Minimize need for visual tracking of target items.
- Reduce number of different choices to perceive/select. Avoid requiring users to press more than two keys at one time. Present choices in prompts (voice or graphic) and menus rather than typed commands or memorized sequences.
- Minimize conceptual complexity of control techniques (e.g., memory). For single switch use, stepping is simpler than scanning. Mouse use may be difficult for persons with poor spatial motor skills. Use representative codes whenever possible (such as Y/N) rather than arbitrary (such as 1/0).
- Present choices in similar methods across different tasks. Provide global task-related command structures that are consistent across applications rather than multi-step commands (e.g., the same command sequence to cancel or revise a chosen activity).
- Avoid switching contexts or operating modes without obvious cues. Provide consistent feedback about system status and how to change to a different status, particularly how to exit system.
- Limit the possible number of results associated with a given action (such as pressing a particular

switch). One key access is best for menus, directions, help, exit, or re-entry, if keycodes are distinct. Single switch activation is simplest if performing consistently the same action (such as signalling Y/N) rather than multiple actions (starting/stopping action, selecting from menus).

PRESENTATION FORMAT

- Reduce visual and auditory complexity of the output display. Concentrate on one idea per display. Use blank space to focus attention. Monochrome displays are usually easier to read than color.
- Provide voice output for instructions and task feedback to reduce reliance on reading to understand and complete task. Any information presented by voice should be easily retrievable for review.
- Minimize use of transitory signals. Beeps and noises should be primarily for attention or reinforcement. Program should allow turning off auditory signals.
- Highlight important information on the display, and group information in meaningful ways. Displays should highlight abnormal conditions, new information, or essential concepts only. Possible methods include animation, contrast, color cueing, directive arrows, boxes, flashing lights, large print.
- Provide direct task-related feedback to the user. Evidence suggests that system responses are best only for indicating errors in learning tasks, not for providing both positive and negative performance feedback. Avoid use of printed feedback for nonreaders.
- Utilize task-related motivation features as much as possible in addition to stimulus/response reinforcement (usually pictures or graphics). Use game features, competition, fantasy, intermediate goals, humor, or novelty to vary task and maintain interest.
- Limit the number of activities occurring simultaneously. Upper memory limit for nondisabled persons is approximately seven conceptual units.
- Match the means of concept representation to user skills (words, pictures, symbols, voice, noise, animation). Allow flexibility in display creation and manipulation to account for individual differences in abilities and learning styles.

INFORMATIONAL CONTENT AND PROMPTING

- Match the vocabulary and grammar level used in speech or writing to the user's linguistic and cognitive abilities. Maintain a consistent difficulty level across system instructions, voice output, and user manuals.
- Minimize the number and complexity of concepts represented at one time. Provide repetition or sequential presentation of difficult concepts rather than multi-concept displays.
- Allow flexible time limits for task completion. Prompt user at excessive delays on possible actions or problem solutions.
- Simplify sequences of activities necessary in controlling task. Command menus should be organized hierarchically, such that infrequent or one-time tasks (such as volume or speed changes) are activated separately from main program tasks. Increase automatic or default system control of nonessential details.
- Include on-line memory aids and help screens. Feedback should suggest appropriate procedures and indicate possible sequences of action. System should prompt the user if error patterns are persistent, by breaking down the task into smaller conceptual units. Present only memory aids relevant to the immediate task on screen, with a standard access point for further information not currently displayed.

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WANDERING BEHAVIOR IN ELDERLY PEOPLE

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ABSTRACT

A video tape observational methodology and sophisticated location detection system was developed to capture behaviors demonstrated by dementia patients residing in a nursing home. This line of research provided definitive knowledge about the nature of wandering and the variables with which it was associated. The use of this technology in observational methodologies leads to more accurate data collection, less observer bias, and the development of quantitative analysis techniques.

INTRODUCTION

The system was developed to collect data in the *Wandering Behavior in Elderly People* research project and used radio-tracking equipment manufactured by COTAG.™ Video and computer technologies were integrated into the system to record the wandering behaviors exhibited by certain individuals in a nursing home. A wandering patient may enter unsafe areas and/or exit the nursing home without being aware they are in danger. These patients are unable to refrain from this behavior and are at risk of injuring themselves.

DISCUSSION

To capture these behaviors, each subject wore a watch-sized radio transponder on his or her ankle or on their wheelchair. Each transponder contained a microchip that was individually programmed with a unique code, enabling each subject to be identified. These normally dormant transponders were activated only when interrogated as they came within range of a transmitter system with loop antennae and supporting electronics.

The loop antennae were installed around doorways, beneath floormats and strategically placed throughout the building. This placement created "zones" on the residential floors, exits, and high traffic areas of the nursing home. One or more video surveillance cameras, microphones and audio speakers were also strategically placed within the range of each "zone." This allowed the wandering behavior of each test subject to be monitored and recorded for later analysis.

Each interrogator zone system contained both a "transmitting" and a "receiving" antenna. The "transmitting" antenna, driven by an RF oscillator, generated a constant 132 KHZ interrogation field. This interrogation field activated the coded transponder when it came within range. When interrogated, the transponder generated a 66 KHZ signal in response, which was detected by the "receiving" antenna.

Cables were routed from each "zone" to a central location within the nursing home. This location contained the brain of the system consisting of electronic circuitry called an "interrogator," an AT-compatible personal computer, a bank of surveillance-type video cassette recorders, and a PA system.

Whenever a subject entered a "zone", his or her transponder was activated and identified itself to the system. The "interrogator" received and processed the signal to determine the subject's I.D. number and the zone number where the wandering behavior was occurring. The computer assimilated these data, along with the date and time, into a log. At the same time, the "interrogator" activated the VCR associated with its particular "zone" so the event could be recorded. The date and time of the event was automatically inserted onto the video tape. The VCR was then deactivated a specified amount of time after the wanderer had left the vicinity.

During the intervention phase of the study, a voice message was automatically activated when wandering occurred. The message called the individual by name and instructed the wanderer to "go back." These voice messages were stored in the computer by use of a digital voice card. These messages were converted to analog and routed through the PA system to the audio speaker in the particular "zone" where the wandering event was taking place. Different voices and voice messages were evaluated and determined that short, simple messages were most effective.

SUMMARY

This system allowed the behavioral researchers to identify and classify wandering behaviors in institutionalized elderly nursing home residents. The system allowed unobtrusive, unbiased observation of this behavior as it occurred and permitted different interventions to be tested and evaluated.

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4.2

IDENTIFICATION OF HOME SAFETY PROBLEMS AND TECHNOLOGICAL SOLUTIONS FOR OLDER DISABLED PERSONS

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INTRODUCTION

Aging brings with it an increase in the relative proportion of persons with disabilities (Haber, 1986). Disabilities often make it difficult for the older person to function safely and puts them at risk for injury. Safety at home is of particular concern, since the vast majority of older persons live in non-institutional settings. The effective incorporation and use of technology are central to the safety and rehabilitation of the older person in order to maintain independence, prevent further disability, and prevent institutionalization. Although technology has been widely used to solve problems of rehabilitation, the unique needs of the older person have generally not been considered in developing new technologies or modifying existing ones (Holstein 1987).

The ultimate goal of this project is to develop a sub-center on technology within the Rehabilitation Research and Training Center on Aging at Rancho Los Amigos Medical Center. The first phase of this five year project focuses on investigation of three accident categories commonly encountered in the homes of disabled older persons. A set of critical problems for each accident category will be identified. Next, commercially available products designed to resolve those problems will be selected. These products will then be tested in the home and/or simulated setting. This product testing may reveal gaps where available technology does not meet the needs of the aging person. A third phase of the project will be conducted to fill such problem-product gaps through modification and development of products.

Dissemination activities will be an important component in later phases of this project. These will include production of a home safety resource notebook, preparation of articles for publication, the development of product utilization workshops and the presentation of information at conferences concerned with geriatrics, rehabilitation, or human factors.

PROBLEM IDENTIFICATION

There are a multitude of potential in-home safety problems for disabled elderly. Therefore, one important beginning task of the project was to limit the universe of problems to be studied. After a review of existing literature as well as the National Electronic Injury Surveillance System (NEISS) data, it was decided to focus the project on problems of **burns/scalds, medication intake errors, and falls**. These three accident categories represent a majority of in-home safety problems experienced by older disabled persons (NEISS, 1987).

Within each of the primary accident categories, more specific factors are being investigated. Here again, it was decided to narrow the potential factors for investigation by designating which activities for each accident category were most salient. For burns/scalds, cooking and bathing were selected. Taking oral medications was selected for medication intake, while walking, transferring and climbing were selected for falls. Using the above structure, a survey was constructed to obtain specific problem responses from health care professionals who have some experience doing in-home assessments with older persons. These experts were selected from national mailing lists of the American Occupational Therapy Association, American Physical Therapy Association and organizations for registered nurses. Experts were asked to list the environmental, functional and psychological problems for each activity related to the three accident categories. In addition to more common problems, they were also asked to list any unusual problems related to the given activities they may have observed in clients' homes.

The results of the survey will be presented. This survey data will have three qualities of particular value. First, the results will guide the selection of products to be studied in later phases of the project. Secondly, to the best of our knowlege, there is no systematic information describing what those professionals who do the actual in-home assessments of older persons feel are the most critical safety problems. Third, this survey data will allow us to compare perceptions of the professionals with existing literature and the NEISS information.

PROBLEM-PRODUCT MATCH

Based on the environmental, functional and psychological problems identified by the experts, a search for products which have potential for solving these problems will be conducted. ABLEDATA, as well as catalogs which present products for the general population will be among the resources used to identify products. As many of these products as possbile will be obtained for clinical evaluation with older disabled persons. Product testing will involve an extended trial of the device by older disabled persons and/or their families within their homes or a simulated environment. The testing will focus on how well the products address the environmental, functional, and psychological problems of older disabled individuals.

Home safety problems of relevance to the older person and which have no existing solution through technology and/or products will be identified. This information will be categorized according to the extent of engineering involvement needed. The first category will include existing products that require only a minor or simple modification to be more useable and/or acceptable by the older person with a disability. These products will be ones where the method of modification is fairly obvious. Engineering involvement with these products will be minimal. The manufacturer may be contacted and ideas for modifying the equipment will be shared. Simple sketches or drawings may be provided to the manufacturer to clarify an idea.

The second category of products will include those which need modification to improve appropriateness, but the definitive solution is not known. Products in this category will need some engineering development. Generally, this development will involve design and production of a prototype modification and trial with potential users. The availability of the product for modification and engineering resources will dictate which products can be modified.

The third category will include problems where products do not currently exist, but development of new technology seems feasible. This category will involve a research and development phase and may result in the fabrication of a prototype for actual trial. As in the second category, the engineering involvement with the development of new technology may be limited by available resources.

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5.1

WHEELCHAIR DESIGNS FROM THE THIRD WORLD:
A Radical Change in Cushion Design

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ABSTRACT

For over nine years we have been working with wheelchair builders in Third World countries to design and build state-of-the art, light weight folding wheelchairs. By working with well established organizations of disabled activists and small businesses and restricting our design to chairs built with low-capitol tools and locally available materials, we have had a fair degree of success in 15 countries around the world. In this paper we will discuss some of the recent changes in our design, and ask for the assistance of RESNA members in seeking solutions that have sofar eluded us.

DESIGN CRITERIA FOR CHAIR DESIGN

The high cost of lightweight wheelchairs has put them out of reach of most of the Third World's disabled people. Poorer disabled people have either gone without a wheelchair or have used locally manufactured models that are often heavy, confining, and lacking in many of the necessary features of state of the art chairs. A state-of-the-art sports chair can be made for roughly the same price as the cheapest hospital style chair; there is thus little reason for a person to start out with a chair that is less functional than the best.

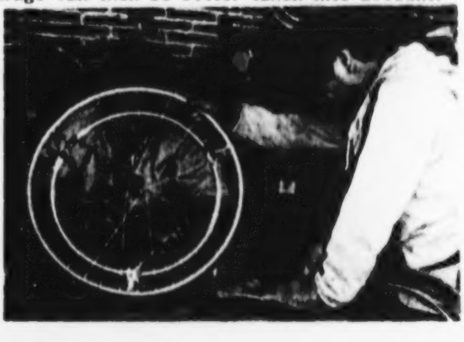
The most difficult obstacles to the users, however, are not the chairs themselves. Wheelchair users must solve various environal problems in order to successfully use their chairs. These include getting chair repairs, taking advantage of public transportation and finding seat cushions that work in tropical conditions. There are some specific areas that must be considered when designing chairs for Third World wheelchair riders. The chair is more useful if it folds in order to be easily transported on bus or burro. The footrests should fold so the rider can pull in close to beds and tables, and the armrests should not block lateral transfer. The chairs must be stable, have good traction; chairs should be light and agile enough for the rider to travel over rough ground, yet be strong enough to withstand unpaved roads and tough handling. When parts do fail they must locally repairable. Last but not least, these wheelchairs must be affordable. Fancy wheelchairs are of little use if few can afford to buy them.

Our chair design uses a flexible folding frame, similar to E&J's first patent, to help maintain traction and control over rough ground. The chair is a full-featured model, with handrims, brakes, retracting footrests and non-obstructing armrests. The hub of the rear wheel is a new flangeless design that is cheaper and easier to make than most.

Suitable commercial front tires and wheels are not available in most countries; the builders have had custom wheels made of aluminum, polyethylene, PVC, spun sheet metal, and wood, with varying degrees of success. We are looking for better designs and methods of fabrication.

Most chairs in use today are significantly wider than their optimum size. These chairs severely limit their rider's level of independence by blocking access to narrow doorways and reducing the rider's pushing efficiency. Historically, when chairs have been mass produced far from the point of sale, the riders have typically been stuck with too-wide "one size fits all" chairs.

Because our chairs can be made locally with a minimum of capital investment, it is much more likely that the builder will tailor the chair to a given rider. The customer's width, height, disability level, seated posture, and intended usage can then be better taken into account.



NEW DEVELOPMENTS

The **Hand Rims** of a typical wheelchair are connected to each rear wheel rim by a total of 48 components that are formed in 16 punch press operations and are installed in 48 separately drilled holes. This type of hand rim tends to work loose.

In our latest design this dos not happen because we use nothing but a single bolt in place of each hand rim connector. This bolt is welded to the hand rim, bent 90 degrees and fastened to a hole drilled in the wheel rim (see photo).

High speed caster flutter cuts wheelchair user performance and can be hazardous. We have previously reduced caster flutter by using frictional dampers, but these dampers make it noticeably more difficult to swivel the caster.

An engineering student in the SFSU graduate RET program has designed a radically improved anti-flutter caster. His device uses viscous damping between concentric tubes within the caster barrel. This eliminates flutter without creating noticeable resistance to low speed caster swivel. In its simplest form, this innovation can eliminate flutter without adding additional parts. The lubricant in the caster swivel bearings is simply replaced with a very highly viscous silicone anti-shear compound. We are now checking the anti-shear characteristics of available compounds in several developing countries in hopes of finding one which works (see paper by Dwight Johnson in '89 RESNA Proceedings)

RELATED PROBLEMS

An **adequate wheelchair cushion** provides good support, is well ventilated, is light-weight, is inexpensive and lasts a long time with few repairs. These requirements, although a critical need for most wheelchair users, have not been met in most developing countries. We have been making cushions with a multi-layered corrugated cardboard base that has been custom molded to the user's shape. Recently, we changed our method of pre-cutting the cardboard base to enable us to better fit and control the posture of each user. Our previous method was to cut away an indentation of a standardized shape underneath a person's seated area, and then to mold the dampened cushion base to the shape of the user.

This method does not work for some people, so we were forced to change our technique. In order to size and locate the cutaway, the person now first sits on a dampened, uncut cardboard base in a relatively erect, comfortable posture. A gentle imprint of the person's weight-bearing protruberances forms on the surface of the cardboard, showing exactly where the person was sitting.

The cardboard immediately around the weight bearing area is outlined and cut away with a keyhole saw. The base is dampened again, and the user sits on the base until the cardboard has fully taken their shape. When the base has been dried and painted a foam cushion is put on top to further equalize the pressure.

UNSOLVED PROBLEMS

The survival and rehabilitation rate of quadriplegics in developing countries is rapidly increasing. This disability, among others, necessitates the use of a powered chair for independent mobility. The maintenance of an **electric wheelchair** can cost more than a skilled worker's total annual wage in Third World Countries. The costs of the motors, gear boxes and control systems must be drastically reduced before there is any possibility of providing electric chairs to most of the world's potential users.

Variable height wheelchairs are indispensable in at two common situations: passing through low doorways of housing in some areas and participating in work or social activities carried out at the floor level. Numerous designs for variable height wheelchairs have been proposed but none so far have provided adequate height change without compromising critical design features of standard chairs.

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5.2

Orthotics and Prosthetics in Madagascar and Nicaragua

J. Martin Carlson, M.S. (Eng), C.P.O.
Self Employed

ABSTRACT

The circumstances and needs present in each of the developing nations is unique for many reasons so opportunities to be helpful vary greatly from one nation and setting to another. The technology, institutions, and program pre-existing in the developing nations should be respectfully studied before the introduction of different technologies and programs. Orthotic and Prosthetic service provision programs in Madagascar and international programs toward improving those services appear not to be centralized. In Nicaragua there is a high degree of centralization.

My visits to Madagascar and Nicaragua were for two weeks in each case. My experience in Madagascar was in a government-operated children's polio hospital in the central highlands of the island nation. In Nicaragua, my perspective comes from the Aldo Chavarria orthotic and prosthetic facility in Managua.

Polio is still a severe problem in Madagascar. Children arrive at the Centre de Reeducation Motrice (CRM) in Antsirabe, Madagascar, typically with very significant lower extremity contractures. Since the availability of orthopedic surgery is very limited, serial and wedge casting is the way they reduce those contractures to the point where lower extremity orthoses can provide the means for practical ambulation. The hospital employs five orthotic technicians and about an equal number of shoemakers. Three of the orthotic technicians have been trained at Associacao de Assistencia a Crianca Defeituosa (AACD) in Sao Paulo, Brazil, with training expenses underwritten partly by the World Rehab. Fund. The salaries of the technicians at CRM are paid by the Madagascar Government, not by a foreign aid agency or missionary organization---a very significant fact.

Orthoses at CRM are constructed of basic materials: steel and aluminum bar and sheet stock and leather. Hand tools and machinery resources are few and in poor repair. Orthotic joints were of the clevis or lap type and fashioned on-site. The orthoses they construct are practical and appropriate to their resources. Significant service/durability problems exist to the extent that they often do not have metal bar and sheet stock of necessary dimensions.

Circumstances in Nicaragua are very different. The constitution of Nicaragua lists health care as one of the human rights of its citizens and virtually all orthotic and prosthetic care for this nation of three million people is provided through a government facility at the Aldo Chavarria Rehabilitation Center in Managua.

Nicaragua's rehabilitation challenges and problems are many. The war with the Contras has produced many amputees and other disabling injuries among both the soldier and civilian population. In addition, they have the usual injury and disease-related disabilities including a large post-polio population. Better polio immunization programs have, in recent years, eliminated new polio cases.

The orthotic and prosthetic facility at Aldo Chavarria is a cooperative venture of the Nicaragua Ministry of Health and the International Committee of the Red Cross (ICRC) based in Geneva Switzerland. The technical manager, Mr. Esteban Barahona, and the ICRC coordinator, Mr. Michelle Leroi, spent several hours answering numerous questions and giving the history and working philosophy of the facility.

In 1984 the ICRC and the Nicaragua

Ministry of Health launched their cooperative program at Aldo Chavarria. The goals of that cooperation were to develop a service and training program simultaneously and to develop designs using locally available materials as much as possible. This was to enable the ICRC to eventually withdraw technical and financial support leaving behind an equipped facility with trained staff and an operating cost that the government could afford. They have proceeded far and well toward achieving those goals.

The facility at Aldo Chavarria fabricates a very serviceable SACH type prosthetic foot. They manufacture all of their prosthetic knee-shin components and set-ups and they manufacture all of their orthotic joint components. They make these things from basic wood, plastic, foam and metal sheet and bar stock which is inexpensive and available in Central America. The designs require minimal fabrication tooling and their knee-shin set-ups are very comparable in function and durability to the adjustable friction knees we use in North America. They still must purchase some things such as wrist units, and outside knee joints from outside the Central America region. When we asked what were their currently most difficult technical problems, they answered: 1. Developing a more cosmetic and durable foam and cover material for endoskeletal prostheses; and 2. Repairing prostheses fabricated elsewhere. In order to build an ongoing service that Nicaragua can afford and be proud of, they will continue to push their prosthetic designs farther toward utilization of locally available materials and technology. They will continue to standardize on those designs and fabricate them in quantity.

Orthotic designs utilized metal and leather. We saw a few spinal orthoses and the balance were lower extremity orthoses. They had both steel and aluminum bar stock and used them as durability and weight efficiency needs dictated. Knee joints were fabricated by sandwiching the side bars (steel and aluminum) between steel side plates. That arrangement with three rivits forms the joint. Ankle joints are formed by a simple overlapping and riviting of the side bar to the upper portion of the stirrup. Ankle motion stops were formed easily in a fashion that can be seen in O & P atlases covering shop fabrication of metal ankle joints. They reported adequate durability using aluminum (one of the precipitation hardenable alloys, I presume) bar stock 20 mm wide by 5mm thick for side bars. Aluminum calf and thigh bands are from 25mm by 2.5mm bar stock. Steel side bars are made from 20mm by 4mm bar stock and the sandwich joint side plates are of 2.5mm thick steel bar or sheet stock (steel stock should, of course, be a product of one of the mill processes which produce a work-hardened micro structure.). The orthoses were attached by solid stirrups to very well-made shoes crafted by the shoemakers there at Aldo Chavarria. The orthoses were appropriately designed, well-crafted and durable.

The Aldo Chavarria facility has a staff of eight Nicaraguan supervisors and technicians and four ICRC instructors. Eleven students split their time between classroom and laboratory.

Anybody proposing to be useful and helpful to people in developing countries should approach any action or program with a great deal of thoughtfulness. The government of a struggling, developing country cannot afford to duplicate any programs or services outsiders are willing to provide. Similarly, any outside agency setting up any health care delivery program in parallel with an existing or developing indigenous program will tend to destroy the latter. The outside effort must be planned very carefully to be supportive and aimed at building local capability and affordability.

ACKNOWLEDGMENTS

The author's travels were self-sponsored. Subsistence expenses in Madagascar were sponsored by the Centre de Reeducation Metrice. Activities in Nicaragua were facilitated by Project Minnesota/Leon (a people-to-people sister state program). J. Martin Carlson, MS (Eng.) CPO, 6005 Kellogg, Edina, MN. 55424

5.3

Technology Overseas

J.F. Garrett
World Rehabilitation Fund

The World Rehabilitation Fund was founded in 1955 as a non-profit organization to improve the quality of life of all persons with impairments throughout the world, especially those in the emerging nations. It assists governmental and voluntary agencies to establish, improve and expand rehabilitation services for the disabled. It provides technical assistance, training, exchange of experts and information. It has official relations with the World Health Organization. It has operated over its history in over 150 countries around the world and maintains two regional offices (Puerto Rico for Latin America and India for the subcontinent) as well as offices in Lebanon and Honduras for its special projects there.

Although it covers almost all disciplines and subjects in its program, remarks here will concentrate on the area of rehabilitation engineering and particularly prosthetics/orthotics:

- for over twenty-five (25) years the Fund has trained technicians in six month programs in AK and BK prostheses and orthoses in several centers around the world (eg. Sao Paulo, Brazil).
- this program has now been replaced by an experimental two-year associate degree program in the Dominican Republic developed in cooperation with New York University and adapted to Latin American needs.

Trainees have come from thirteen (13) countries in Latin America; and the second course, now underway, has trainees from twelve countries. A special feature at the first graduation was a special seminar on *Lower Limb Prosthetics and Orthotics: A Team Approach* in which a physician and physical therapist from each of the sponsoring organizations participated.

- equipment and books have been provided to workshops to which trainees have returned
- special short-term training in recent developments in P and O has been conducted for persons in WRF projects for Lebanon, Cyprus and Nicaragua as recent examples
- technical assistance in evaluating existing or determining the need for prosthetics/orthotics service programs under a variety of auspices (eg. UNDP) in areas such as Gaza and the West Bank, Vietnam, Thailand, Armenia and the subcontinent.

The Fund appreciates the cooperation and participation of the P and O community around the world in providing its expertise in these activities. It is hoped that you would continue your participation in this and also take advantage of our interchange of experts program.

CROSS-CULTURAL TECHNOLOGY TRANSFER FOR REHABILITATION AND INDEPENDENT LIVING

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ABSTRACT

Futurist author John Naisbitt has suggested that we all need to master three subjects to be prepared for the future: computers, English, and Spanish (1). Fortunately, the first two pose no problem for U.S. professionals, especially engineers. The same cannot be said for our ability to appreciate the "global village" and to communicate even in our own country that is becoming increasingly bilingual. This paper describes a volunteer organization through which you can get interesting, first-hand bicultural experience while applying your engineering expertise to immediate and challenging problems of disability in developing countries.

PARTNERS OF THE AMERICAS

Founded 25 years ago, Partners of the Americas is the largest private, voluntary, people-to-people organization in the Western Hemisphere. It is a network of 58 partnerships between states/areas in the U.S. and nations/areas in Latin America and the Caribbean. Through the individual partnerships, thousands of volunteers from all walks of life work together to design and implement projects that promote economic, educational, social and vocational development while fostering inter-American friendship and understanding. Project areas include: agriculture, arts, community development, education, emergency preparedness, health, rehabilitation, sports, and youth. The rehabilitation program is called Partners Appropriate Technology for the Handicapped (PATH). This paper will present an overview of PATH, its mission, and project possibilities.

PARTNERS APPROPRIATE TECHNOLOGY FOR THE HANDICAPPED (PATH)

Ten years ago, Partners of the Americas saw the need for establishing a program focus and framework for the development and dissemination of technologies that could be readily applied to the daily living challenges of people with disabilities in communities with few, if any, technical or professional resources. Thus began the PATH program that involves professionals, para-professionals, family members and persons with disabilities in community-based programs that encourage informal, low-cost applications of rehabilitation knowledge. PATH has a lifespan scope (prevention, early identification and intervention, living and learning with disabilities, and working with disabilities). It encompasses all types of disabilities and attempts to avoid diagnostic categories that can make project planning and implementation stereotyped or fragmented.

More than 120 sites throughout the southern partner countries serve as PATH Resource Centers. These clearinghouses of audio-visual and print resources contain practical information that is continually being supplemented with new recommendations of ideas, people, programs, publications and technologies. A specific example from the last category is a wheelchair, designed by Ralph Hotchkiss, that is fabricated from readily available materials (e.g., bicycle tires) and that has greater durability in the rough terrains common in the rural environments of developing countries.

OPPORTUNITIES FOR INTER-AMERICAN EXCHANGE IN REHABILITATION ENGINEERING

Most U.S. partnerships have a standing PATH committee which, in collaboration with its southern counterpart, devises projects that respond to identified rehabilitation needs in the latter's country. Typically, projects could be described as low-budget but creative. This is not surprising, given the fact that as an unfunded volunteer organization, the assets of Partners are totaled in the contributed time and talent of the members. However, there is a national office of Partners in Washington, DC (2) that secures funds from government agencies, corporate foundations and private individuals which it funnels to partnerships based on written proposals for specific projects. There are three types of awards: (a) Travel grants cover round-trip airfare and limited incidental travel expenses to visit the partner country for an approximate period of ten days to two months. Travel can be in either direction. For example, a professor from Portland State University in Oregon obtained a travel grant to help install the first acoustical testing facility in Costa Rica. (b) Training grants give a professional or technician from a southern partnership partial support for the costs of travel, tuition, materials and living expenses to obtain advanced training in the partner state. The training proposal originates in the southern partnership and is responded to by the northern partnership which designs an appropriate program of experiences and then hosts the trainee for a period ranging from a few months to two years. Acceptable training sites are not restricted to academic institutions and may include private industry, professional associations and governmental agencies. (c) Small grants provide up to $5,000 for a project conceived and proposed by either side of a partnership but implemented collaboratively in the southern country. Such a grant supplied CERVOC, the first vocational rehabilitation center for persons with physical disabilities in Guatemala, with tools and materials for its training programs in wheelchair manufacture, radio/TV repair and wood crafts. CERVOC was established at the request of the Guatemalan Partners when they were informed that their Alabama associates raised $50,000 from small contributions in response to the devastating earthquake in Guatemala City in 1975. With that money, the Alabamans puchased and shipped a prefabricated building which members from both partnerships assembled themselves.

MAXIMIZING IMPACT THROUGH INTER-ORGANIZATIONAL SUPPORT AND NETWORKING

Certainly, the essence of Partners is the personal interchange across cultures and countries. However, each member is also a treasure of more local affiliations, contacts and resources that should be accessed for his or her Partners activities so as to widen the circle of mutual beneficiaries and to increase the multiplier effect of the effort. As chair of the Louisiana PATH committee, the author is currently involved with the Louisiana Occupational Therapy Association (LOTA) in a fruitful example of such networking. To demonstrate an ongoing commitment to international outreach, LOTA decided to sponsor OTs from a few countries to attend its annual conference. LOTA was prepared to pay only part of the trainees' expenses while in Louisiana for the conference and follow-up visits to facilities. Furthermore, they were encountering difficulty recruiting an OT from Louisiana's partner, El Salvador, where there are literally a handful of formally trained OTs and, hence, no OT association. LOTA contacted Louisiana Partners for assistance with funding and finding an OT candidate for its offer. Our respective resources dovetailed nicely; Partners recruited a Salvadoran OT and subsidized her transportation through a travel grant. The 1990 national convention of OTs will be held in New Orleans, so we have contacted our counterparts in partnerships and OT chapters across the U.S. to encourage them to negotiate similar cooperative agreements. Indeed, we encourage all relevant professional associations to investigate corresponding opportunities to share the resources of their memberships and continuing education activities.

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An Optical Joystick for Electric Wheelchairs

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Abstract

Conventional joysticks use two potentiometers to produce a variable voltage proportional to the deflection of the lever used to guide a wheelchair. A new implementation using a light emitting diode and four photodetectors is proposed in this paper. The advantage of this implementation is that, while keeping the circuit simple and the cost low, it produces a more reliable performance because the only motion is mechanical. The electric signals are obtained from solid state devices that do not wear and, unless subject to voltages outside of their range, should last longer than any other wheelchair component.

I. Basic Components

The primary disadvantage of the standard wheelchair joystick is the use of potentiometers employing sliding electric contacts, which inherently wear out with use. Other types of joysticks have been proposed, and some are available in the market, using principles such as variable reluctance, the Hall effect, etc.[1,2,3]. These are relatively expensive or require very small joystick motion, or both. In other words, they are pressure-actuated, instead of motion actuated. It has been determined experimentally that users prefer a moving stick, which gives them a good feeling for the direction of motion. An optical joystick based in light emitting diodes-photodetectors is reliable, economical and uses a stick with motion identical to that of a standard joystick. The basic components of the optical joystick are a light emitting diode (LED) and four photodetectors (PD). The LED emits infrared light, and the photodetectors, when connected to a power supply and a closed circuit, generate a current. The current is proportional to the infrared light incident on the base of the photodetector, and the light, in turn, is proportional to the directional command of the joystick, Fig.1.

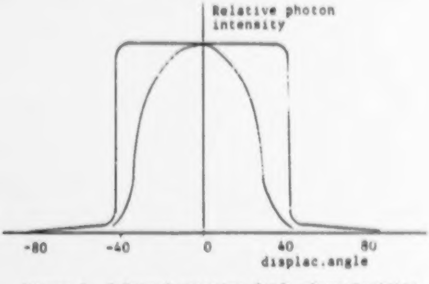


Figure 1. Infrared emitting diode characteristic

LEDs with different emitting characteristics, both in wavelength and in angular distribution, are available to suit many types of applications.

Similarly, PDs with different sensitivities to both angle of incidence and light wave length, are manufactured to suit most practical needs, Fig.2. Infrared sensors were chosen because of long life, low power consumption and their inmunity to visible ligth. After testing several pairs, the opto-diode OD-88OW and photodetector OP593 pair were chosen, the first because of near linear light intensity vs angle relationship and the second because of its wide angle receptor characteristic (its output current is nearly constant for incident light over a wide abgular value.) The block diagram of the complete circuit is shown in Fig.3.

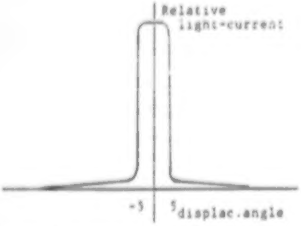


Figure 2. Photodiode characteristic

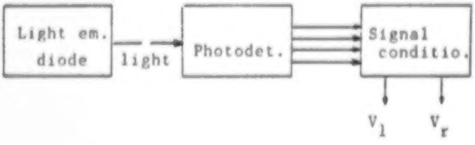
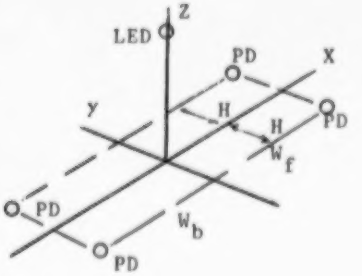


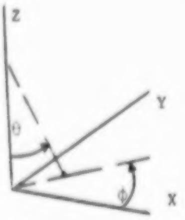
Figure 3. Block diagram

II. Geometric configuration.

The joystick employs an LED mounted on the stick and four PDs fixed in the joystick box, Fig.4. The joystick configuration of Fig.4 was tested for several values of H and W. Fig.5 shows the results for a perpendicular distance LED-PD plane D=0.95 cm. Fig.6 shows the geometric configuration of the PDs and LED based on these tests. Notice that the PD location is not symmetric for forward/backward motion. This allows increased speed in the forward direction, which is safer and preferred by users.



(a) Geometric configuration



(b) Directional angles

Figure 4.

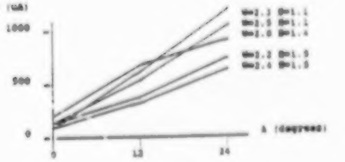


Figure 5. Test results: I_c vs α

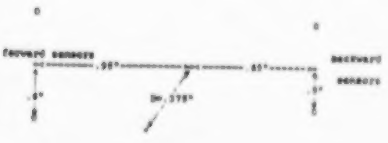


Figure 6. Device location

II. Signal conditioning.

The output of the PDs is a current. This has to be transformed into a proportional voltage. In addition, only two signals are needed, one for the right hand motor and one for the left hand motor. The polarity of the output voltage indicates the direction of rotation of the respective motor. A simple operational amplifier circuit permits to obtain the following relationship :

$$V_o=K_1I_f-K_2I_b-K_3V$$

K_1 and K_2 are determined by the values of the resistors in the operational circuit and V is a biasing voltage used to obtain $V_o = 0$ when the joystick is at rest.
With the geometric configuration of Fig.6 and the signal conditioning indicated above, the output voltage of the two motors is almost linearly proportional to solid angle of deflection. Results are indicated in Table I, where θ and ϕ are as defined in Fig. 4.

TABLE I

OUTPUT VOLTAGES AS FUNCTION OF POSITION

θ	ϕ	V_r	V_l
0	0	0	0
40	0	2.4	2.3
80	0	5	5
-40	0	-2.5	-2.4
-80	0	-5.1	-5
40	45	0.8	3.4
80	45	2.7	5.0
+40	270	3.0	0.8
+80	270	5.0	2.8
-40	225	-3.5	-0.6
-80	225	-5.1	-1.8
-40	135	-0.6	-3.2
-80	135	-2.0	-5.1

III. Conclusion.

In this paper we have described a joystick for electric wheelchairs and other applications based on light-emitting-diode/ photodectector pairs. The circuit is economical, reliable and light weight, and could advantageously replace potentiometer-based joystick.

Acknowledgement
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MODIFICATION OF A PROPORTIONAL JOYSTICK TO INCORPORATE ACCESSORY SWITCH OUTPUTS

6.2

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INTRODUCTION

High level quadriplegics with residual upper extremity function can often learn to control proportional hand joysticks, using specialized splints or other orthotic techniques. However, these orthoses may complicate the existing difficulties with operating the controls for other wheelchair-based systems such as the power recline or an environmental control unit (ECU). The best solution to this problem is to integrate control of all of these functions into a single user interface, i.e., the joystick. Unfortunately, until very recently, a commercial system of this type, for proportional hand joysticks, has not been available.

This paper presents a solution to this problem that was designed and built for a C2 quadriplegic. While commercially available systems should obviate the need for this approach in the future, this concept is potentially useful as a retrofit for many existing wheelchair systems.

RATIONALE

Commercial systems with integral wheelchair control and alternative functions have been available for a number of years. Unfortunately, these have been limited to proportional chin joysticks and switch-input controls. Both of these methodologies have significant disadvantages in comparison to proportional hand joystick systems. Switch control is undesirable because the degree of wheelchair control provided is inferior to proportional systems which provide continuous adjustment of speed and direction. Proportional chin joystick systems are cosmetically unappealing and limit head and neck movement while operating the wheelchair. Thus, a proportional hand joystick system is generally preferred for driving a wheelchair.

In order to operate accessory devices, a number of switch outputs must be available. For individuals with strong upper extremity function, this is not an insurmountable problem, since a number of standard switches can be mounted in proximity to the joystick. However, for someone with marginal control for driving, it may be impossible for them to remove their hands from the joystick in order to operate accessory switches. Switches may be mounted at other sites, such as over each shoulder or on the headrest but these can seriously limit the user's freedom of movement. Generally, it is most desirable to incorporate additional switch outputs into the proportional hand joystick.

METHODS

In the absence of an available commercial device, a custom system was developed to add discrete switch outputs to a proportional hand joystick. Operation of the system incorporates three modes: 1) A *drive* mode, 2) an *accessory* mode, and 3) an *off* mode. A block diagram of the system is shown in Figure 1.

A momentary single pole ("mode") switch is required in order to sequence between operational states. When the system is in drive mode, power to the wheelchair is on and movement of the joystick produces proportional output for driving the chair. If the user activates the mode switch while in *drive* mode, the system steps to *off* mode, in which movement of the joystick has no effect and power to the wheelchair itself is disconnected. An important safety consideration is that the mode immediately following *drive* is always one in which all outputs are disabled and the mode switch functions as a "kill" switch. This is particularly important when hand splints are used and the individual may be mechanically tied to the joystick. From *off* mode, activating the mode switch advances the system to *accessory* mode, in which displacement of the joystick provides switch outputs. For example, forward and reverse movement can be used to control a power recline, and left and right may be coupled to an ECU. Power to the wheelchair is disconnected in *accessory* mode.

The technical aspects of the system are as follows. Functionally, the system consists of four units: 1) a switch (which can be located for head activation or elsewhere) to cycle through the three joystick control modes, 2) a mode display unit mountable anywhere on the chair, 3) the adapted joystick, and 4) the control electronics. The joystick can be modified in one of two ways: by interfacing with the existing wheelchair control system or by the addition of an external system to detect the mechanical displacement of the stick. The latter choice is preferable as it does not require extensive technical knowledge of the electronic design and functioning of the chair controller, nor is it necessary to disassemble and perform elaborate modifications of a commercial device and void the warranty.

For the working prototype (see figure 2), a toroidal magnet was mounted on the axis of the joystick within the protective rubber bellows. Four magnetic reed switches were positioned in a plastic housing so that each would actuate in one of the four primary directions. Reed switches are slender glass tubes with two feromagnetic reeds entering from either end and overlapping in the middle. They are activated by a magnetic field of the proper strength and alignment. They have some advantages over mechanical switches in that they are very small and require no mechanical linkage for operation. They are, however, brittle and have a limited spacial range of sensitivity. It is necessary (but difficult) to position them so that they trigger before the joystick is at full displacement and so that they open again when the joystick is in neutral.

The second functional unit is the controlling circuitry used to step between modes. It is based on a 4017 CMOS ring counter. Incoming pulses from the mode switch are conditioned and counted by the ring counter which recycles on every third pulse. The outputs of the ring counter are coupled to relays which, in the corresponding mode: 1) engage the reed switches only, 2) engage wheelchair power and pass the proportional joystick signals directly to the chair controller without modification (in this mode, it is totally transparent to the wheelchair controller), and 3) nothing. With this approach, the number of modes can be increased to include any number of *accessory* states by re-programming the ring counter and using a larger number of output relays.

DISCUSSION

The augmented joystick system was a successful solution to a specific problem. It blended cosmetically and functionally into the rest of the power mobility system and was successful both from a clinical and an engineering standpoint. The design and development of such a custom device is naturally labor-intensive. There are, however, a number of improvements which should be incorporated into a future version were it to be considered.

It is most desirable to preserve the manufacturer's warranty and avoid opening the joystick even for mounting purposes. Thus, the switch array should be attached superficially to the top of the enclosure This would also make it more widely applicable to a variety of joystick models. It would also be an improvement to use solid state magnetic sensors or an optical system rather than reed switches. These would require more circuitry but a much simpler and more resilient mechanical design. An optical method is potentially simpler to install and does not require the addition of a magnet. See figure 3 for a drawing of the mechanics of such a system.

CONCLUSIONS

Fortunately, a hand joystick control with the needed accessory outputs has recently appeared on the market. This eliminates the need to perform custom adaptations for new systems. On the other hand, this does not abate the existing need for a simple retrofit for earlier model controllers. It is not unreasonable to consider a commercial add-on version of a system such as that described that incorporates accessory switch control into a standard joystick.

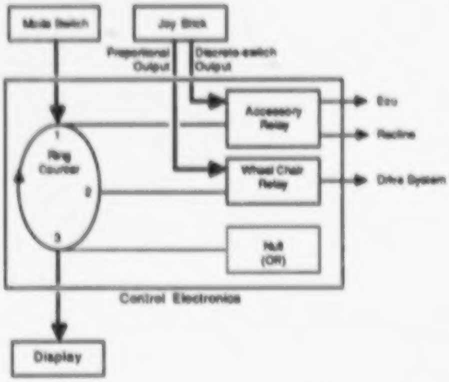

Figure 1. Block Diagram of Accessory Switch System

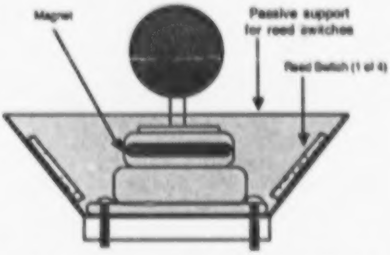

Figure 2. Reed Switches and Housing mounted on Joystick

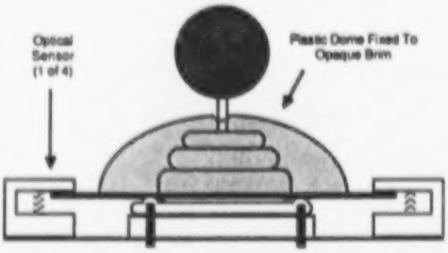

Figure 3. Optical Accessory Switch Design
The dome/brim is free to slide in two dimensions

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6.3

EVALUATION OF A DAMPED JOYSTICK FOR PEOPLE DISABLED BY INTENTION TREMOR

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ABSTRACT

A 2-degree-of-freedom joystick with externally adjustable viscous damping has been designed, built and evaluated. Experimental results showed that the amplitude of intention tremor decreases with the use of viscous damping without degradation of purposeful movement. Testing to date has included video dynamic tracking and path-following tasks, and wheelchair path-following tasks, with three subjects, two with tremor and one control.

INTRODUCTION

Pathological tremor affects approximately 800,000 people in the U.S. Tremor can be caused by benign familial conditions; degenerative neurological diseases such as Friedreich's Ataxia, Parkinson's Disease or Multiple sclerosis; or from injury to the cerebellum or brainstem.

One clinical classification is known as intention tremor. It occurs during performance of a voluntary motor task and usually increases as the person approaches a target. The research described in this paper was conducted with people disabled by intention tremor.

Many people with tremor are wheelchair users and have great difficulty controlling the joystick of a powered chair. Accurate control of wheelchair velocity is impossible due to the large amplitude oscillations produced by tremor.

JOYSTICK DEVELOPMENT

In response to this problem a viscously damped joystick was designed by Rosen. The governing principle was resistive force proportional to velocity. Purposeful movements at a low velocity require relatively low muscle forces, whereas high frequency tremor oscillations would be resisted by a large force, resulting in a selective reduction of tremor.

In 1985, a prototype was built in this lab by Katy Laffey and Norman Berube [1]. A conventional potentiometric proportional control joystick was positioned inverted over a chamber filled with a high-viscosity fluid. A spherical drag element in the fluid, attached to the shaft, provided a damping constant of 0.8lbf/(in/sec) when the handle was moved. A U.S. patent was awarded to M.I.T. in August, 1987. The prototype was tested with one tremor subject, using a one-degree-of-freedom dynamic tracking task, with favorable results.

In October, 1987, the joystick was redesigned. The strength of the joystick's structural members was increased to accommodate the larger forces due to the high-viscosity fluid. The primary design change was the addition of externally variable damping. The spherical drag element was replaced by three nested cylinders, which can be extended and retracted by unscrewing a lock nut and rotating the spherical joystick handle. The effect of increasing the length of the drag element, increasing the velocity of the drag element by moving its centroid further away from the bearing, and increasing the moment arm result in a damping range of 0.4lbf/(in/sec) to 2.20lbf/(in/sec) (a ratio of almost 5). A mechanical counter located inside the handle counts from 0 at the lowest damping setting to 315 at the highest, to allow accurate reproducibility of desired settings. Because the drag element is cylindrical, damping is the same in any direction.

EXPERIMENTS

Three subjects were tested, using both the viscously damped joystick and an otherwise-identical undamped joystick. Two subjects had tremor, due to MS and head injury, and one was able-bodied. Most experimentation was done with computer-generated tasks.

A two-degree-of-freedom pursuit tracking program presented a moving rectangular target on the screen and the subject was asked to match the rectangle with a crosshairs that is controlled by the joystick. X and y displacements of the joystick were instantaneously mapped to the xy movements of the crosshairs. The pseudorandom target signal consisted of the sum of 6 sine waves with a maximum frequency of 0.5Hz.

A second video task was a simulation of actual wheelchair control. At the start of a task an aerial view of a path was shown on the computer screen with a wheelchair icon at the start of the path. The mapping from joystick to the computer screen was programmed to simulate actual wheelchair control, i.e., joystick position controls velocity. In response to joystick movements the path translated and rotated relative to a fixed wheelchair icon, providing an approximately driver's-eye-view. Three paths were used for testing: a path with two left turns, one with two right turns, and a third consisting of a serpentine.

All three subjects were tested at four damping conditions: umdamped, the lowest available damping setting, the highest setting, and an intermediate setting. The order of all tests and damping levels was randomized.

RESULTS

Data from the pursuit tracking task showed a statistically highly significant decrease in tremor in the presence of damping for both tremor subjects. The tremor subjects, when assisted by damping of approximately 1.4lbf/(in/sec) showed performance comparable to the undamped normal control. Damping did not decrease tracking fidelity and in fact increased it dramatically for one of the subjects. Figure 1 shows position versus time plots for one of the tremor subjects with and without damping. Figure 2 shows a similar plot for the normal control with an undamped joystick. This data is typical.

Data from the video path following task showed a significant decrease in tremor without degradation of purposeful movement for one disabled subject. The other tremor subject was unable to master the task.

Experiments were also run with the joystick mounted on an electric wheelchair. Subjects were asked to follow a fixed path on the floor as fast as they could travel. The wheelchair position was monitored by the Selspot/TRACK system. The data from this task was inconclusive due to mechanical oscillations of the support structure for the Selspot LED. Further wheelchair tests are planned.

DISCUSSION

The research outlined in this paper demonstrated in two subjects that viscous damping selectively decreases tremor in two-degree-of-freedom tracking and path following tasks. This result is consistent with the outcome of this group's earlier work with one-degree-of-freedom damping [2]. Continued research will be needed to test the generality of our findings. Future wheelchair tracking tasks will also include dynamic targets since we wish to assess improvement in control of velocity due to damping. Accurate control of velocity is particularly important when driving in the midst of pedestrian traffic.

It should be noted that there are several reasons for considering the mechanical damping approach as an alternative or complement to the electronic filtering provided in some powered wheelchairs. First, from a cosmetic point of view, a person with tremor is likely to prefer that tremor be reduced *at the hand*.. Secondly, mechanical damping could in theory reduce the neurological tremor source for some types of tremor rather than simply attenuating the resultant movement. Third, analysis shows that if a dead zone is present in the center of the joystick range, it or the limits of joystick movement can clip the tremor oscillations. This clipping results in a shifting of the tremor sinusoid and generates a DC offset. Electronic filtering cannot remove this DC component.

The video tasks may be viewed not only as a research method but also as a potential clinicians' tool. It is hoped that a correlation will be established in future work between the results from the video tasks and actual wheelchair driving performance. If data supports this expectation, the effectiveness of a damped joystick can be established for a client from video-based assessment without the need for wheelchair tests and monitoring instruments. If the most effective damping setting is found in this way, a prescription can be written for a fixed-damping joystick.

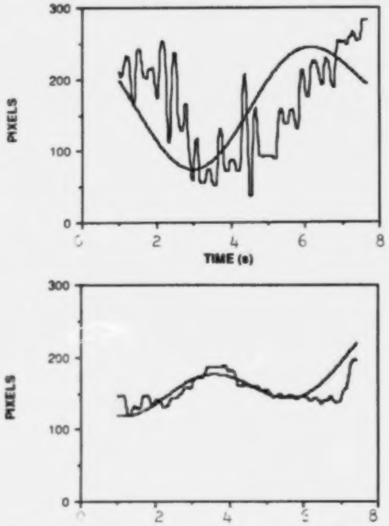

Fig. 1- Tremor subject's tracking performance with and without damping.

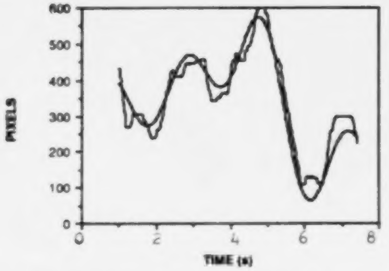

Fig. 2- Control subject's tracking performance without damping.

ACKNOWLEDGMENTS

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A TRAINING AND EVALUATION TOOL FOR REMEDIAL CAUSE AND EFFECT DEVELOPMENT

6.4

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ABSTRACT

Clinicians continually make efforts to provide powered mobility aids to individuals with more complex disabilities, realizing the positive impact mobility has on the individual's overall development. Aside from physically accessing the interface to a powered mobility aid, the individual must demonstrate comprehension of basic cause and effect relationships as prerequisites to the safe operation and prescription of the powered mobility aid. If the individual does not possess these skills, remedial instruction is required. This paper describes the development of a training and evaluation tool which can be administered in the home setting. The progress of the individual in the training program can be monitored and the relative difficulty of the training program altered via modem link.

INTRODUCTION

The Interface Programme, at the Hugh MacMillan Medical Centre (HMMC), performs an average of 100 powered mobility assessments per year. Individuals referred to the Programme are physically impaired and have complex needs which usually cannot be satisfied by smaller community mobility clinics in conjunction with local vendors. Often their ability to control a powered mobility aid is adversely affected by severe cognitive deficits. In 1986 there were 86 such assessments resulting in 40 prescriptions for powered mobility aids while 46 of these individuals could not demonstrate the necessary proficiency and combination of cognitive, spatial and perceptual skills for the safe operation of a powered mobility aid. The continued non-independent mobility status of these individuals reduces their opportunities to acquire these skills.

It has been subjectively determined that individuals who possess the necessary manual dexterity to manipulate a microswitch joystick may not have the cognitive skills to comprehend and differentiate the somewhat subtle movements of the joystick handle. Joystick operation may be too complex for them to learn without an intermediate provision of controls. In the past this has been done through the provision of separate switches, one for each of the directions FORWARD, REVERSE, LEFT, RIGHT and ON/OFF control. Initially it may be necessary to limit the switches to only one direction, such as FORWARD. Scenarios are required, with one-on-one instruction, for the individual to experience the vestibular and visual effects of activating the switch and some consequences of not releasing the switch on command. As proficiency with the switch increases LEFT and RIGHT switches may be added. Eventually a REVERSE switch will be provided. Prescriptions are generated based on physical skills and subsequent remedial training is provided to develop the necessary cognitive skills.

The period of time required for an individual to learn the necessary skills for independent mobility varies widely. Due to the labour intensiveness of the remedial instruction process, clinical time is limited for extensive training over extended periods. Additionally, the family's transportation and lodging costs must be considered when setting the number of assessment and training sessions. It is often recommended that the individual return for re-assessment after a period of time with the hope that there is sufficient stimulus in their environment to promote the development of the necessary skills. This skill development has not always occurred and methods are being sought to provide a remedial instruction package that can be administered in the home setting with some parent assistance and instruction. A need then exits to be able to adjust the complexity of the training package based on the individual's skill development without necessitating the individual's return to the clinic.

OBJECTIVES

1) To develop a hardware trainer to monitor user switch inputs, provide visual cues to guide switch selection, provide auditory and visual stimulus in response to correct switch selection and facilitate trial data transfer and storage.
2) To provide a linking program between the Trainer Unit and an MS-DOS IBM compatible computer. The computer provides the trial configurations, medium for data storage and the modem.
3) To provide a means for data transfer and training program modification via a modem link without the need for computer literacy.

TRAINING PROGRAM

The training program was designed for persons who are developmentally delayed (mentally retarded). The pressure on schools and institutions to mainstream developmentally delayed persons has increased the need and demand for powered mobility for persons who presently are not considered to be suitable candidates for powered mobility. Learning in developmentally delayed persons is characterized by: (a) slower acquisition, requiring more practice and frequent repetitions; (b) need for small learning steps; (c) poor or very limited generalization; (d) short, wandering or perseverating attention. These were accounted for in the design of the training program by developing two components. These are: Switch Training, and; Generalization.

Switch Training

The first component consists of 7 training steps to teach the operation of from 1 to 5 switches. The switches are mounted on an individualized 76cm x 76cm tray. Large (20mm diameter) LED lights are mounted directly above the switches. Four switches have green LED's and one switch has a red LED. Each switch controls the activation of one toy. In Step 1 only one green switch is available. Only when the LED's are on is the switch active and does the toy work. In Step 2 the switch with the red LED is added. The red switch is always activated last and only after the green switch(es) are turned off. Succeeding steps either add another switch or allow for practicing switches already mastered. In the more advanced steps multiple green LED switches can be made available simultaneously or in sequence. The duration for which a switch LED remains on before timing out can be pre-programmed. An uniform one minute reinforcement time was chosen for initial testing. Measurements of time to activate, switch activated, toy type, and numbers of inappropriate switch activations are collected and stored for transmission to the HMMC.

Generalization Task

At regular intervals during the six months training session the generalizability of the switch training will be evaluated. The Trainer, computer and tray will then be installed on a powered wheelchair. The participants will drive the powered wheelchair using their own training tray with the number of switches mastered up to that time. The participant will operate the chair in a large space and will be asked to follow the directions provided by the lights on their training tray. The software program used for this transfer of training test is the same as that used for switch training. The measurements collected during this are identical to those obtained in the switch training stage.

THE SYSTEM

Lap-top Toshiba T1000 portable computers with an internal 1200 baud modem and a RS-232C communication adapter are used for running the main training program, recording the training sequence data and providing researchers with access to the trial data.

The Trainer Unit was developed based on the single chip microcomputer 68705R3 which receives trial configuration data from the Toshiba computer, runs the trial, collects data and transmits the data back to the Toshiba for storage to disk. Inputs are provided for up to five user input switches. Outputs are provided to drive large light emitting diodes to prompt the individual when a particular switch is enabled for activation. Five additional outputs were provided to control separate toys in response to correct input switch activation. The toy outputs use 7 pin DIN connectors which provide a 3.0 volt supply to the toys and also allow a toy identification code to be read from the mating adapted toy plug.

Custom, large area, low activation force, membrane switches were chosen as the user input interface to the system. Each of the five switches has a different bright background colour with a large black arrow oriented to indicate direction. Other switches be used with the system.

THE TOSHIBA COMPUTER

Loading the main program requires the user to merely turn on the power switch. The program prompts the user initially to input a single keystroke to select either the training program or the modem communication program.

In the training program a separate file is maintained on the disk which contains information relevant to the subject being tested. Such information as the subject's name, study commencement date, current training step, the last session completed and the number of trainings completed are contained in this file. It is this file which determines the complexity and the duration of the training program. The file can be modified remotely by researchers via a modem. A separate directory on the disk is set up to sequentially store data from the various trials as they occur.

A single keystroke is also required to load the PROCOMM V2.4.2 modem communication program. The command file configures the modem for COM2 and establishes HOST mode requiring the family only to connect their computer to the telephone lines with a modular jack. A researcher then calls the family's telephone number and the computer automatically answers. PROCOMM's upload path has been configured for the data directory of the current disk. Access can be gain to the DOS level by the researcher to modify the training program parameters as desired. The RS-232C communications adapter is configured as COM1 and is the bi-directional communication link between the Toshiba and the Interface Unit. Connections to the Toshiba computer consist of a power supply connection and a 9 pin "D" ribbon cable. There is only one program disk and that can remain in the drive at all times.

THE INTERFACE UNIT

The Trainer Unit is contained in a plastic enclosure mounted under the wheelchair tray which incorporates the interface switches. The exterior of the enclosure has the 5 DIN connectors for the toys, a 9 pin "D" connector for RS-232 communication, a 9 pin "D" connector of opposite gender as an active low output and a power supply connection. The microcomputer in the Trainer Unit performs all the switch closure counting, event timing, toy control, auditory and visual feedback operations, and data conversion for transfer to the Toshiba. Switching voltage regulators are provided for the microcomputer supply and toy output power so that only one AC adapter is required.

PRESENT STATUS

The training modules and support materials, as described, have been completed. Training and evaluation with 20 subjects is scheduled to commence shortly. The anticipated outcomes of the project are the creation of a home and school based training package for persons who require pre-mobility training before they can become independently mobile. It is also a tool that clinicians can use to remotely monitor and modify an individual's specific training program, as necessary.

ACKNOWLEDGMENTS

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POWERED WHEELCHAIR CONTROL, ASSESSMENT, AND TRAINING

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ABSTRACT

Learning to operate a powered mobility device is similar to learning to walk. There is a period of tentative apprehension and reluctance to move for fear of falling. A comfortable and supportive learning environment is essential for success and provides time for building confidence.

The Wheelchair Simulator is presented as a tool that will assest therapists in the assessment and training of powered mobility driving skills (1,2). The Simulator is designed to augment in-chair training by giving pre-powered mobility users the opportunity to become familiar with the mechanics of operating a powered wheelchair in a comfortable, relaxed, safe, and stimulating learning environment using computer generated three dimensional graphics and sound.

INTRODUCTION

The importance of independent mobility

The ability to move independently from one point to another is something we take for granted. As infants, we experience the desire to move and explore our environment. Without the ability to move and explore, much of our development would be thwarted. For an individual who experiences a limited ability to move around, it is crucial that an assisted method of independent mobility be provided.

Independent mobility becomes ability: the ability to be a social interactor rather than a passive observer; the ability to choose the parts of the world to explore rather than having them chosen; the ability to test out the environment by defying authority. Choices become a part of life rather than something that is given by others when they feel the time is appropriate.

Powered mobility training

Three methods of training potential users about how to operate powered mobility devices can be identified. In the first two methods, the user is positioned in a mobility device and is given the experience of movement while developing an understanding of how the control mechanism operates the chair (3,4). The third method requires only that the individual be properly positioned, not necessarily in a mobility device, and that the input device (e.g. joystick or switch array) is in the optimal placement for best control (1).

The third method, which is undergoing continued development, is a computer operated wheelchair simulator (2). It is designed to augment in-chair training by giving users the opportunity to become familiar with the mechanics of operating a powered wheelchair is a comfortable, relaxed, and safe learning environment.

DESCRIPTION

The Wheelchair Simulator is written in the C Language for the Commodore Amiga computer - a computer with extensive graphic and audio capabilities. An additional feature is the 9 pin joystick port which allows many of the commercially available wheelchair joysticks and special interfaces to be connected directly to the computer. This is particularly true for the more recent wheelchair models that have been released by Fortress Scientific and Everest & Jennings, Inc.

As the program currently exists, the required computer configuration includes an Amiga computer with one megabyte of Random Access Memory (RAM), an RGB monitor, a second 3.5 inch disk drive, a mouse and a joystick.

The program presently gives therapists the opportunity to design a floor plan that closely resembles part of the user's environment. Walls can be drawn, halls created, doorways inserted and obstacles placed to provide the user with a copy of a real life environment. The user moves through the computerized environment by controlling speed and direction via a joystick or a series of switches connected to the computer. Therapists can choose to have the floor plan presented in a two dimensional display; this allows the user to become comfortable in a maze-like environment before attempting to move through a three dimensional simulation.

The Wheelchair Simulator computer program will consist of two major components: one for the trainee, and the other for the therapists to customize the simulation to the trainee and to evaluate the trainee's performance. The program will be developed to run on the Apple IIgs and IBM compatible computers.

SUMMARY

The provision of powered mobility devices to children and adults in need of independent mobility is a costly endeavour. Prior to the allocation of funding for the purchase of a device, there is the need for a detailed assessment of the individual's skills, proper seating and positioning, as well as an evaluation of their best control methods. Present methods of control, which make use of alternate switching devices, allow anyone with a reliable, consistent physical movement to access powered mobility devices.

The Wheelchair Simulator is designed to enable therapists and users to evaluate the optimal control interface before ordering the mobility aid. In this way, various control interfaces can be evaluated before a prescription is made. The Simulator provides a safe environment in which to test the control interface. When trying to determine which method is best, fear is removed as a variable in the decision making process. The Simulator also provides a controlled environment, allow- each interface to be evaluated using exactly the same simulation; hence, the therapist is able to make a more objective decision when choosing the best control method.

The prototype version of the Simulator has produced a great deal of interest. Improvements to the program and its transfer to other personal computers is required. The systematic evaluation of the Simulator package in a true clinical environment by therapists is necessary.

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6.6

AUTOMATED WHEELCHAIR GUIDED BY MAGNETIC FERRITE MARKER

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ABSTRACT

A newly-developed automated wheelchair with magnetic guidance sensor is described. This wheelchair, guided by a magnetic ferrite marker laid in/on the sidewalk or floor, permits severely handicapped persons and old people to move about freely, due to the simple operation involved (just pushing a button). This wheelchair is provided with two infrared sensors, for obstacle detection to maintain safety, and an infrared sensor, for stopping at prescribed positions.

INTRODUCTION

Recently, the demands involved in old people's activities in the community are strongly increasing, as society reaches a greater average age. Also, physically handicapped persons, who do not have full control of their body or legs, would like to go shipping, see movies or just get some fresh air. In response to these demands, many kinds of hand-operated (propelled) and electrically-controlled wheelchairs have been developed [1]. However, hand-propelled wheelchairs do not permit riders to go far, since their use is tiring. Also, driving electrically-controlled wheelchairs can be difficult for a handicapped person, especially on a narrow curved road. Therefore, automated wheelchairs permitting simple operation are in demand.

This paper proposes a new automated wheelchair, guided by a magnetic ferrite marker, which permits easy use by any severely handicapped persons and old people. Its running characteristics including safety and functionality have been investigated.

BACKGROUND

Many kinds of hand-operated and electrically-controlled wheelchairs have been developed for physically handicapped persons. The hand-operated wheelchairs are not conducive to traveling very far, since they must be propelled by the occupants arms. Electrically-controlled wheelchairs can be operated by manually controlling their joysticks in a simple form. However, since they require the operator to be skilled in a turning operation and a direction-change operation, it is difficult for severely handicapped persons to operate them skillfully. Therefore, these persons could not use either of these kinds of wheelchair without difficulty.

So far, automated guided vehicle systems using magnetic ferrite markers have been developed by NEC Corporation [2][3].

METHODS

The authors have developed a novel automated guided wheelchair with a magnetic sensor [3], which is guided by magnetic ferrite markers laid in/on the sidewalk or floor. The magnetic sensor consists of an exciting coil (forming a magnetic field) arranged at its center and two detecting (pick-up) coils on its right and left sides (Fig. 1). The magnetic field is set up by the exciting coil and the pick-up coils detect a magnetic field deviation caused by the magnetic ferrite markers. The output signals, obtained by two detecting coils, are subtracted from each other. Since the difference between these detection output signals is proportional to the wheelchair deviation from the center of the ferrite marker laid in a line or curved form, this difference signal permits controlling the wheelchair's steering.

In this wheelchair, a non-linear signal processing circuit (Fig. 2) is used to obtain a steering free operation within a small deviation range, which prevents its oscillation during running operation. Also, a new pulse drive method is used at each initial stage of steering to prevent feed-back running to a small extent. Furthermore, for safe operation, the authors have constructed two infrared obstacle detection sensors on the wheelchair's front. To permit the wheelchair to stop at specified positions, an infrared sensor, detecting the reflection tape marker laid on its floor or sidewalk, has been constructed.

RESULTS

The automated guided wheelchair, with the magnetic sensor on the front, is shown in Fig. 3. The magnetic sensor unit height from the floor is 70 mm. Running experiments have been carried out along a corridor with a soft ferrite marker on the floor. This marker is soft ferrite bound with resin, which is 100 mm wide and 5 mm thick. Even with a man weighing 80 kg, the wheelchair has successfully run along the marker at less than 2.2 km/h walking speed. At higher speed, a feed-back running phenomenon has been observed a little, which should be improved in the future.

Also, when an obstacle (a man) appeared

about one meter in front of the wheelchair, it came to a stop. In this way, the safety function has been confirmed.

Furthermore, it has been confirmed that the wheelchair stops at a predetermined position by detecting the reflection tape marker. When there are several destinations, users can move to the desired destination by counting the number of reflection tape markers, when the wheelchair passes

DISCUSSION

Soft ferrite has a magnetic property. Sensing characteristics are hardly influenced by any pollution or small conductance materials left surrounding it, when this material is used as a marker. Therefore, this kind of marker can be used both inside and outside. An automated wheelchair, guided by this ferrite marker, is a useful tool for increasing the activities range for both physically handicapped persons and for old people. Especially, since this wheelchair permits users to go to a destination by simply pushing a button before starting out, and moves without any special operation by the passenger, severely handicapped persons and persons whose arms are paralyzed can use it easily and travel freely.

CONCLUSIONS

An automated wheelchair (with magnetic sensor) guided by a magnetic ferrite marker laid in/on the sidewalk or floor has been developed. It shows satisfactory operating performance. The wheelchair, which has excellent safety and functionality, has been realized by providing two infrared sensors for obstacle detection and an infrared sensor for detecting a reflection tape marker and stopping at the prescribed positions.

This wheelchair permits easy use by severely handicapped persons. It also allows many users to act freely, even in the future society where the average age is greatly increased.

ACKNOWLEDGEMENTS

The authors would like to thank Drs. I. Sugano and K. Matsumi for their support, encouragement, and useful discussion. Thanks are also due to Mr. Sato, who produced signal processing circuit.

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[3] T. Tsukagoshi et al., “Magnetic Lattice Lane Guide for AGV Use,” AGVS-5, S5-2, 1987.

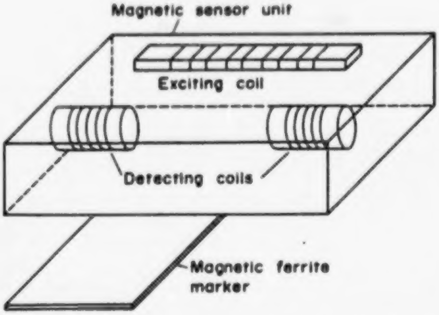
Magnetic sensor unit
Exciting coil
Detecting coils
Magnetic ferrite marker

Fig. 1 Magnetic sensor and magnetic ferrite marker configuration.

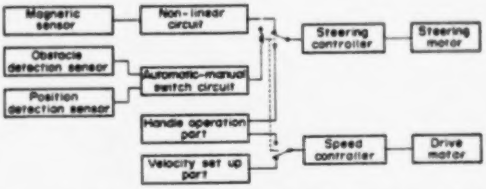
Magnetic sensor
Non-linear circuit
Obstacle detection sensor
Automatic-manual switch circuit
Position detection sensor
Handle operation part
Velocity set up part
Steering controller
Steering motor
Speed controller
Drive motor

Fig. 2 Control circuit blockdiagram for automated wheelchair.

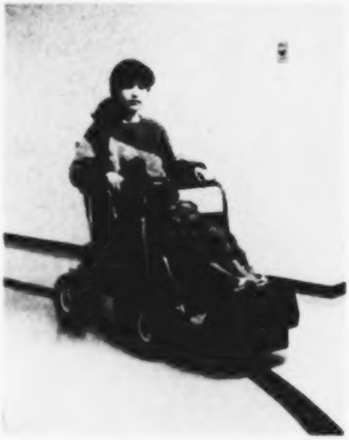

Fig. 3 Automated wheelchair guided by a magnetic ferrite marker.

ADDRESS: NEC Corporation, 4-1-1, Miyazaki, Miyamae-ku, Kawasaki 213, Japan

THE APPLICATION OF RURAL REHABILITATION TECHNOLOGIES
A COMMUNITY BASED APPROACH

7.1

Terry Willkomm, Farm Family Rehabilitation Management Program
The Easter Seal Society of Iowa, Inc.

ABSTRACT

This paper presents a community based approach that can be used in providing rural rehabilitation technologies. Inovative methods on how to identify individuals in rural areas who could benefit from assistive technology and individuals who could assist in providing the needed technology are addressed. Success of the technologies provided and cost effectiveness information are also discussed.

INTRODUCTION

The application of rehabilitation technologies in rural area can be very challenging due to the many barriers that individuals face. These barriers include: isolation from technology-related services; lack of knowledge related to available technologies; few trained professionals who can provide assistive technology services; and limited funding.

To overcome these identified barriers, a one year project, funded by the National Institute on Disability and Rehabilitation Research was developed. The purpose of this project was to demonstrate a community based approach in the development and application of rural rehabilitation technologies.

Through the use of statewide networking activities there were 100 individuals served through this project, who had severe physical disabilities and resided on Iowa farms. All individuals received assistive technology information to overcome at least one barrier related to completing independent living or farm tasks. Forty-six individuals received 91 assitive devices or modifications through the assistance of volunteers, relatives, community organizations, state vocational rehabilitation, and local machine shops.

Technical assistance on how to obtain or fabricate the needed device or modification was provided by The Easter Seal Society of Iowa's Farm Family Rehabilitation Management (FaRM) Program. Follow up was also conducted to determine the success of the technologies provided.

The unique aspects of rural rehabilitation technology are seen in primarily two areas: the nature of the technologies provided and the methods used to provide technology related services. Agricultural worksite modifications and outdoor mobility aids were identified as the most frequently needed technologies. Community volunteers and resources were identified as the most successful and cost effective method of providing these technologies.

IDENTIFICATION OF CLIENTS AND COMMUNITY RESOURCES

Since isolation from needed technology information and services is a frequent problem in rural areas, it was necessary to conduct technology awareness presentations within the agricultural communities throughout the state. A total of 49 awareness presentations were given to agricultural related organizations including Farm Bureau, 4-H, Pork Producers, Public Health Organizations, and civil organizations. In addition, articles and news stories related to rural rehabilitation technologies were published in agricultural newspapers and broadcasted on agricultural television and radio programs. Through media coverage and awareness presentations given, audiences were encouraged to assist in identifying individuals who could benefit from assistive technology or individuals who could assist in providing the needed device or modification. This effort resulted in identifying over 50% of the individuals served by the project and over 60 volunteer resource people throughout the state.

PROVISION OF TECHNOLOGY RELATED SERVICES

An independent living assessment and agricultural worksite assessment were conducted, on site, to identify specific problems and develop assistive technology related solutions. These solutions included commercially available items and devices or modifications which had to be designed and fabricated locally.

Many of the technologies needed were provided trough the statewide volunteer ingenuity network. This network consisted of volunteers who could help donate needed materials to fabricate a device or modification; procure commercially available items that could be donated at no cost; and design or fabricate a needed device or modification. This network included saddle makers, blacksmiths, electricians, physicians, carpenters, farmers, maintenance engineers, and health care professionals. Technical assistance provided to volunteers included: information on the person's physical limitations and capabilities; slides, photographs, mechanical drawings, and video tapes of devices and modifications that have been previously developed; and assistance in obtaining needed materials or resources to construct the device or modification. The type of technologies provided included: tractor lifts and hand controls; modifications to livestock handling facilities; modified hand tools; adaptive independent living aids; farm home adaptations; and outdoor mobility aids.

FUNDING OF REHABILITATION TECHNOLOGIES

Approximately 52% of the technologies provided were obtained, at no cost, through the volunteer ingenuity network. The Division of Vocational Rehabilitation Services and The Community Living Foundation in Iowa paid for approximately 40% of the technologies provided. The remaining technologies provided were paid for by the farm families themselves. It is important to note that none of the technologies were paid for through Medicare, Medicaid, Worker Compensation, or long term disability benefits.

FOLLOW UP OF TECHNOLOGIES PROVIDED

The success of each device or modification provided was determined by the individual's ability to complete the independent living or farm task indentified. Seventy-seven percent of the commercially available items, used for at least 30 days, were successful. Of those devices or modifications that were developed by volunteers and local machine shops, 69% were successful within the first 30 days of use. Approximately 16% of the technologies provided were determined to be unsuccessful after 90 days of use and needed further adaptations or a new device or modification. The reasons why a device was not successful included: improper or no instruction on how to operate the device; manufacturer's defect; the device was not consistant with physical limitations; problems with maintaining the item; and defect in the design.

CONCLUSION

A community based approach in applying rural rehabilitation technologies demonstrates a grass-roots approach of people helping people in every facet of the technology service delivery process. This approach demonstrates to be cost effective due to the need for less staff in design, fabrication, or research of a device. The agricultual media coverage and technology awareness programs were extremely beneficial in identifying individuals in need of technology related services and community resource people who could assist in providing these services.

A disadvantage of a community based approach is the timeliness in which an assistive device or modification is provided. Factors that affect how soon a client can receive a needed technology include the busy schedule of the volunteer; the seasonal demand for repairs at machine shops; stratagies for funding a device or modification, which could take months; and the distance that one must travel to obtain needed expertise. A fully funded mobile rehabilitation engineering shop could significantly increase the timeliness in providing rehabilitation technology services in rural areas.

ACKNOWLEDGEMENT

This project was supported by the National Institute on Disability and Rehabilitation Research, grant number: G008720225.

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A MECHANICAL FEEDING MACHINE FOR VICTIMS OF ARTHROGRYPOSIS

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Tulane University Department of Biomedical Engineering

ABSTRACT

Available self-feeders are often too expensive or ill fitted for the disability. A simple spoon handling mechanism, operated by lever actuated Bowden cables, provides an adaptable system for feeders. This paper describes a design that is currently being used by a child with Arthrogryposis.

INTRODUCTION

Being able to eat in a social setting is crucial for the proper development and happiness of any person. Many handicapped children cannot feed themselves unaided, use, or afford commercially available machines.

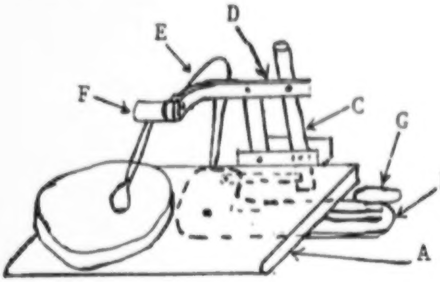
There are several feeding machines currently available from commercial manufacturers that are inappropriate for individuals with arthrogryposis, especially in a rural setting. Some are motorized, requiring a source of power that may not always be available, and some are mechanical. The mechanical devices are cheaper, but still cost about $600 (1). These are suitable for rural use, but are not always adaptable for a given individual's range of motion or for the intelligence, size, and strength of a child.

Ten of every thousand disabled children seen in Mexico (2) and three in the US (3) suffers from arthrogryposis. This defect limits joint motion. Enabling these children to feed themselves is an problem that needs to have a general solution.

DESIGN GOALS

We designed the feeder for a specific client, Lindsay, a four year old who cannot bend her elbows or raise her arms. She has difficulty moving her arms medially, but does have good gripping ability with one hand and can push and pull with shoulder and body action.

The primary goal is to design a machine that is effective, portable, rugged enough for use in a kindergarten cafeteria, and as unobtrusive as possible. Secondary goals include low cost, obvious principles of operation, and maximum adaptability.



Feeder

IMPLEMENTATION

Our design starts with a 9" by 13" wood board (A) stabilized by suction cup feet. A pie plate is fastened with Velcro to a lazy-susan bearing that permits plate rotation. A lever (B), mounted on the underside of the board pivots an upright (C). The upright is paired with a second to support a beam (D) on pivots. This arrangement keeps the beam horizontal as the lever raises and lowers the assembly.

The spoon is rotated by turning a handle (G) at the end of the lever. A cable (E) transfers this motion to a spool (F) mounted at the end of the horizontal bar. When the spoon is pushed into the plate it sweeps along a radius from the center and is held level at the volition of the user. Spoon rotation is limited to protect the mechanism and to keep the spoon in its useful range.

The parts are designed to be assembled for either a right- or lefthanded person, and are made from aluminum to ensure easy machinability, corrosion resistance, and light weight. The lever and cable arrangement is not limited to the current configuration. They may even be made detachable for foot operation, but this is beyond the scope of this work. We estimate that the cost of fabricating the feeder, in small quantities, to be about $300.

DISCUSSION

Lindsay learned to use the machine with coaching on her first session. Colored dots placed on the base and handle worked well as a teaching tool to show proper positions for scooping and food presentation. She can eat pudding, grits, mashed potatoes, and spaghetti. Use with particulate food appears possible by a increasing the slope of the plate edges. She has had the machine for several months and eats two or three meals a day with it.

CONCLUSION

The concept of appropriate technologies is not one restricted to the Third World. Even in our own highly industrialized nation, much of the technology is beyond the economic scope of most people. Our machine is simple, rugged, inexpensive, and performs a sorely needed function. Supplying machines like this to children with arthrogryposis will improve not only their physical capabilities, but also aid their social development.

ACKNOWLEDGEMENTS

Supported, in part, by National Science Foundation, BRAH grant EET-8715696, as an undergraduate engineering design project.
We thank Dianne Patterson, LOTR, for her advice and aid.

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Breaking New Ground Outreach Program

Lauri Logan, Project Coordinator William E. Field, Professor
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BACKGROUND INFORMATION

In 1979, a severely disabled farmer contacted Purdue's Department of Agricultural Engineering requesting assistance on how to modify his agricultural equipment to enable him to continue farming. This initial contact eventually led to the establishment of the Breaking New Ground Resource Center which has become internationally recognized as the primary source of information on rehabilitation technology relating to agricultural worksites.

INTRODUCTION

With support from the Indiana Easter Seal Society, the Center has initiated an outreach program to provide specialized rehabilitation services to rural and farm families throughout Indiana. In addition to working with farmers who are trying to remain productive following a disabling injury or disease, special attention will be given to the needs of children and the elderly living on Indiana farms. Efforts will be made to identify those who could benefit from the appropriate application of rural rehabilitation technology. Those individuals will be assisted in acquiring the needed devices, modifications and resources to live more independently.

The program will also be committed to increasing the awareness level of disability issues in rural areas and providing input concerning public policies which effect the rural disabled.

NECESSITY OF THE PROGRAM

Agricultural production is ranked as the most hazardous occupation in the United States, with the highest disabling injury rate of any industry. One national study revealed that two percent of all full-time farm operators have experienced a permanent disabling injury on their farm. An Indiana farm accident study has shown that one out of every nine farm families experience a farm-related injury each year. Studies by the Breaking New Ground Resource Center indicate that nearly 19 percent of the active farm operators interviewed were no longer able to perform essential tasks due to a disability.

DISABILITIES SERVED

During the start-up period, the Breaking New Ground Outreach Program has assisted individuals with the following disabling conditions:

- spinal cord injuries
- amputations
- back injuries
- arthritis
- hand injuries
- respiratory conditions
- cancer
- stroke (hemiplegia)
- visual impairments
- musculoskeletal disorders

Services, however, are not limited to these disabilities.

SERVICES PROVIDED

The outreach program provides a variety of services which are available to any resident of Indiana. These include:

1. Access to the Breaking New Ground Resource Center - The Center includes a wide array of resource material on making agricultural worksites and rural life more accessible to individuals with physical disabilities. The material includes information on disabilities, worksite modifications, and rural independent living skills.
2. Resource Material - The Center also has a number of technical manuals, reports and audio-visual materials available for purchase. A complete list is available upon request.
3. Breaking New Ground Newsletter - Published when funds are available, the Breaking New Ground newsletter is sent to farmers, ranchers and rural rehabilitation professionals across the United States and beyond. It contains case histories of individuals successfully overcoming the problems of farming with a disability, up-to-date resources, and a listing of upcoming events of special interest to rural and farm families.

4. On-site Visits - To assist in making the farm worksite or home more accessible, a professional from the Breaking New Ground Resource Center is available on a limited basis to make on-site visits. This person will conduct an agricultural worksite assessment, make recommendations concerning possible modifications, provide relevant resource material, and/or contact other professionals or agencies who can provide assistance with a particular problem.
5. Support Group Meetings and Workshops - In order to encourage community based rehabilitation services, the program is involved with establishing support groups throughout the state. These groups will enable individuals, with similar disabilities, to meet together and share concerns and solutions.
6. Public Awareness - The staff will be available to conduct a limited number of exhibits at rural events such as fairs and field days. The purpose of the exhibits is to increase public awareness concerning disability issues and to expose rural residents to available resources.

STAFF

Staff for the Breaking New Ground Outreach Program consists of a project coordinator, part-time student assistants, part-time clerical services, along with the expertise of the Agricultural Engineering Department staff at Purdue University providing direction and consultation. Plans are to develop a network of volunteers across the state to provide technical assistance as needed.

REFERRAL SOURCES

Referrals come from acute care/rehabilitation hospitals, county extension agents, Vocational Rehabilitation counselors, a friend/neighbor, or the individual themselves.

EXAMPLE

A farmer from West Central Indiana incurred a spinal cord compression at the T-10 vertebrae level; paraplegia resulted. He was referred to the outreach program by a professional at a large, acute-care hospital in Indianapolis, Indiana. The family operates a large grain farm.

Modifications to their farming operation have included:

1. Manlifts for their John Deere 4630 tractor and 7700 combine.
2. Hand controls for the clutch and brake on their tractors.
3. Purchase of a four-wheel, all-terrain vehicle for greater farm accessibility.
4. Lowered workbenches and tools in the shop area for greater accessibility and independence.
5. FM, two-way radios for communication and safety.

Vocational Rehabilitation has been instrumental in providing the necessary services and financial resources to obtain the modifications.

CONCLUSION

The number and types of disabilities affecting farm and rural residents are not well documented. There is, however, sufficient cause to believe that the number of persons living in rural areas with handicaps who could benefit from improved or expanded rehabilitation services is significant. The Breaking New Ground Outreach Program bridges the gap between available information/resources and those living in rural areas.

ADDITIONAL INFORMATION

Additional information can be obtained by contacting:

Project Coordinator
Breaking New Ground Resource Center
Dept. of Agricultural Engineering
Purdue University
West Lafayette, IN 47907
(317) 494-5088

or

Indiana Easter Seal Society
3816 East 96th Street
Indianapolis, IN 46240
(317) 844-7919
(800) 458-0841

CREATING AND TESTING AN EFFECTIVE DESIGN FOR A DESKTOP VERSION OF ABLEDATA

Roger O. Smith
Gregg C. Vanderheiden
Jane Berliss
Jennifer Angelo

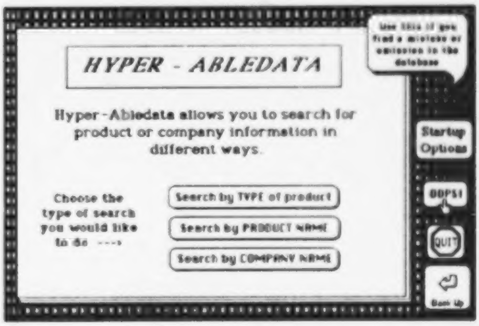
Access to information has long been acknowledged as a critical need in the rehabilitation/assistive technology field, and has been supported as a priority by federal agencies to develop and make this information easily available. Some of the attention paid to information has focused on product information. ABLEDATA, which was available on-line throughout the 1980s, provided product information to on-line computer users. A human broker system provided supplementary access to the information for people who did not have on-line computer capabilities or who were not trained in the use of the database.

The need for accessing current product information is growing rapidly, due to the explosive development of new products in the field. More products need tracking and more information about each product is becoming necessary. For a rehabilitation professional to deliver competent service today, they must consider all of the proper alternatives in the application of rehabilitation/assistive technology. This requires accessing a product database in order to comprehensively review, compare, and locate product options. Several barriers existed in the old database access methods. The on-line ABLEDATA and human brokerage systems required that the individual have either some computer technology sophistication, or substantial time to access university libraries, medical libraries, or an ABLEDATA broker. A data search could also be relatively costly. If a therapist was simply trying to compare rocker knives, they would not deem it cost-effective or time efficient to spend $5-20 and half an hour to several hours obtaining information to identify the various rocker knives available. Rather, they would simply open a catalog with which they were familiar and order.

HYPER-ABLEDATA

Hyper-ABLEDATA as a desktop system was unveiled at the RESNA conference in 1988. Since then, it has become a component of the ABLEDATA services run by the Adaptive Equipment Center at Newington Children's Hospital in Connecticut. The Hyper-ABLEDATA system contains the entire ABLEDATA rehabilitation and assistive technology database, programmed in Macintosh HyperCard. (A version for IBM PC and compatible computers is also in development.) Features of Hyper-ABLEDATA include "user-friendly" components selected for their human factors benefits. These include entry and expert level use with a simple menu-driven design incorporating HyperCard buttons for intuitive access (Figure 1). Thus, the HyperCard screens are set up to provide direct searching of specific data as well as to permit an individual to browse through the product database to sort through the information and increase their general awareness of available products.

Additionally, Hyper-ABLEDATA provides a context-sensitive help box within each of its screens (Figure 2). As the user moves the pointer around the screen, the help box displays a message showing what function each "button" on the screen performs.



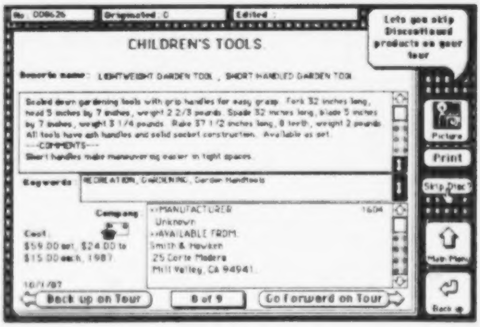
HYPER - ABLEDATA

Hyper-Abledata allows you to search for product or company information in different ways.

Choose the type of search you would like to do --->

Use this if you find a mistake or omission in the database

Figure 1



No.: 008626 Originated: 0 Edited:

CHILDREN'S TOOLS

Generic name: LIGHTWEIGHT GARDEN TOOL, SHORT HANDLED GARDEN TOOL

Scaled down gardening tools with grip handles for easy grasp. Fork 32 inches long, head 5 inches by 7 inches, weight 2 2/3 pounds. Spade 32 inches long, blade 5 inches by 7 inches, weight 3 1/4 pounds. Rake 37 1/2 inches long, 8 teeth, weight 2 pounds. All tools have ash handles and solid socket construction. Available as set.
---COMMENTS---
Short handles make maneuvering easier in tight spaces.

Keywords: RECREATION, GARDENING, Garden Handtools

Cost: $59.00 set, $24.00 to $15.00 each, 1987.

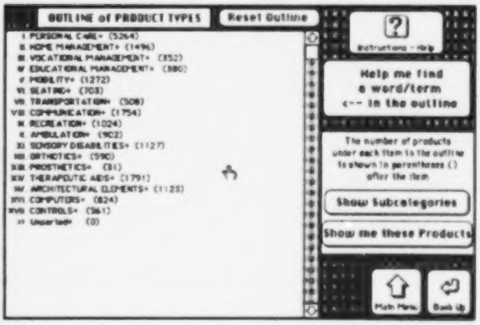
Company:
>>MANUFACTURER 1604
Unknown
>>AVAILABLE FROM:
Smith & Hawken
25 Corte Madera
Mill Valley, CA 94941

10/1/87

Lets you skip Discontinued products on your tour

Figure 2

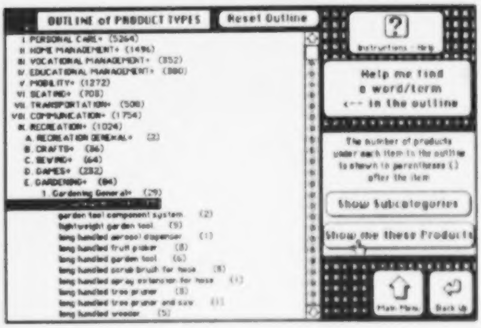
Perhaps one of the most significant features in the Hyper-ABLEDATA design is the implementation of a new search technique. In contrast to the Boolean and command driven methods common in on-line databases, the capabilities of HyperCard have permitted a gestalt presentation, where the information user can see the entire database on one screen as they are wandering through the information. This gestalt presentation is provided in Hyper-ABLEDATA under the "Search by Type of Product" option, where a product is found not by its name or manufacturer, but by what function it serves. A hierarchical outline of descriptive terms provides the base for this search technique. Figure 3 shows a closed outline of the entire ABLEDATA product set, while Figure 4 shows an expanded view of one section of the database.



I PERSONAL CARE+ (5264)
II HOME MANAGEMENT+ (1496)
III VOCATIONAL MANAGEMENT+ (352)
IV EDUCATIONAL MANAGEMENT+ (380)
V MOBILITY+ (1272)
VI SEATING+ (703)
VII TRANSPORTATION+ (508)
VIII COMMUNICATION+ (1754)
IX RECREATION+ (1024)
X AMBULATION+ (902)
XI SENSORY DISABILITIES+ (1127)
XII ORTHOTICS+ (590)
XIII PROSTHETICS+ (31)
XIV THERAPEUTIC AIDS+ (1791)
XV ARCHITECTURAL ELEMENTS+ (1123)
XVI COMPUTERS+ (824)
XVII CONTROLS+ (561)
>> Unsorted+ (0)

The number of products under each item in the outline is shown in parentheses () after the item

Figure 3



I PERSONAL CARE+ (5264)
II HOME MANAGEMENT+ (1496)
III VOCATIONAL MANAGEMENT+ (352)
IV EDUCATIONAL MANAGEMENT+ (380)
V MOBILITY+ (1272)
VI SEATING+ (703)
VII TRANSPORTATION+ (508)
VIII COMMUNICATION+ (1754)
IX RECREATION+ (1024)
  A. RECREATION GENERAL+ (2)
  B. CRAFTS+ (36)
  C. SEWING+ (64)
  D. GAMES+ (232)
  E. GARDENING+ (84)
    1. Gardening General+ (29)
      garden tool component system (2)
      lightweight garden tool (5)
      long handled aerosol dispenser (1)
      long handled fruit picker (8)
      long handled garden tool (6)
      long handled scrub brush for hose (8)
      long handled spray extension for hose (1)
      long handled tree pruner (8)
      long handled tree pruner and saw (1)
      long handled weeder (5)

The number of products under each item in the outline is shown in parentheses () after the item

Figure 4

THE NEED FOR TESTING HYPER-ABLEDATA

The four goals of Hyper-ABLEDATA are:

1) Increase the availability of ABLEDATA to healthcare and education professionals and technology end-users;
2) Decrease the amount of expertise required to locate needed technology product information;
3) Decrease the time resources required for accessing product information (increase the speed); and
4) Decrease the cost of obtaining the information.

Based on beta tests and preliminary field use, Hyper-ABLEDATA appears to be reaching its goals. Empirical data have not yet been obtained, however, which will compare access systems available, amount of expertise needed, speed of accessing information, and information access cost-effectiveness, however, have not as yet been obtained. A handful of specific research studies are needed to identify the true effectiveness of Hyper-ABLEDATA. Studies which compare the speed of Hyper-ABLEDATA against on-line and print versions of the information would be helpful. Studies which clarify the amount of experience with clinical practice, computers, the Macintosh, HyperCard, and Hyper-ABLEDATA that is necessary to effectively use Hyper-ABLEDATA would help identify the amount and quality of up-front training required for optimal Hyper-ABLEDATA use. Other studies needed are cost-effectiveness comparisons of Hyper-ABLEDATA versus other access methods, and quantification of the costs related to various information dissemination methods.

PILOT TESTING OF HYPER-ABLEDATA ACCESS SPEED

To begin the process of investigating some of these information access issues, a pilot study has been performed to identify a baseline on information access speed when using Hyper-ABLEDATA.

The purpose of this pilot study was to obtain a baseline access rate for users of Hyper-ABLEDATA. Three types of data were collected from students in two university clinical training programs which incorporated technology training components. First, students used Hyper-ABLEDATA to answer simple, direct-search questions, such as finding the cost of a given product, locating where a product can be obtained, and ascertaining the number of a certain type of product available. A second data set solicited responses to general types of questions surrounding product information, such as: "Ignoring the discontinued items, how many of a certain type of technology product are currently available?" or: "Who are the key manufacturers of a certain type of technology?" or: "What is the general range of costs for a certain type of item?" A third data set collected pertained to the students' subjective impression of using Hyper-ABLEDATA in comparison with print media containing the same information. Questions ascertaining how much a student was willing to pay for Hyper-ABLEDATA versus a printed version, how much fun they had using Hyper-ABLEDATA, how confusing the system appeared to them, etc., are included within this data set. The particular printed media compared with Hyper-ABLEDATA were Volumes 1, 2, and 3 of the Rehab/Education ResourceBook Series from the Trace Center (which contain 1300 items; Hyper-ABLEDATA contains 15,000 items).

The initial results of this pilot study indicate that Hyper-ABLEDATA is meeting its intended goals. The studies also identified ways in which the database could be made easier to learn use, particularly with individuals not already familiar with the Macintosh computer. Additionally, a range of access times have been acquired as a base from which to design future comparative research.

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IMPLEMENTATION OF AN IMAGE-BANK FOR ASSISTIVE DEVICES

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ABSTRACT

Technical devices that can assist a person with a handicap have become widely spread. It then became necessary to organise the information on the available products and services in databases. This paper describes the design of a relational database, in which the content of textual information of the objects in the databank is illustrated by means of images. These images are shown on a VGA computer screen. In addition, two or three calibrated perspective views allow the user of the data-base to retrieve self-defined 3-dimensional information (distances, angles, ...) from the pictures on the screen. The accuracy of these measurements is better than 1%.

Although at the moment the storage of information is foreseen on a WORM disk, the data-base is organised in such a way that optimal use can be made of new data storage media, such as erasable optical disks.

INTRODUCTION

Because of both the large diversity of disabilities and the divergent intensity in which they occur, numerous devices have been constructed to eliminate or reduce the handicap that is caused. As an immediate consequence, it was necessary to assemble the available information in nationally or internationally organised databases throughout Europe and America. Attention is now focussed upon the problem of an adequate description of the device, helping the D-base user during his process of information retrieval.

Problems encountered by organisers of databases for assistive devices were twofold. On the one hand, large efforts had to be made in defining the items and the structure of a data-base, with which diverse products could be described and categorised accurately. On the other hand, the content of the D-base should correspond to the questions of the user, who is interested in possible solutions for a functional limitation rather than the description of a device. It was thought that images of the assistive devices in a computer data-base could facilitate this retrieval process to a large extent.

Recently the Veterans Administration has contributed considerably to this idea by using a video-disk as part of an information system for assistive devices. However, the technology used implies a relatively high cost during the preparation of the material, for the manufacturing of the (first) disk and for the hardware, required to retrieve information from the disk.

Because information on diverse dimensions of a technical device is often of crucial importance in the choice of the device it is necessary to provide the appropriate data. However, it is not feasible to include detailed measurements in a textual database, since it is difficult to anticipate the user's requirements and since this would demand a large effort both to define the different items for the different types of objects and to collect the data. It was decided that calibrated pictures in the data-bank could contribute to overcome these problems.

METHODS

In order to dispose of both descriptive and quantitative information (dimensions) on technical aids at an affordable cost, a research project has been supported by the Flemish Government. This project has led to an information system as described further. It consists of a commercially available data base (Omnis Quartz), which offers a number of possibilities required for our application, together with additional and self-developed software tools.

The relational data-base combines some fourth generation facilities such as multiuser access, powerful retrieval functions, extensive programming instructions and high flexibility in the rearrangement of the data structure. Moreover, the same data-files can be run both on IBM-PC/PS and Apple Macintosh II micro-computers.

Data is organised in a relational structure in order to enhance both the data collection procedure and the quality of the information retrieval. Products are described by type specifications, functional description, user groups to whom they apply and free text information on special characteristics.

These data is related to names, addresses, etc. of manufacturers and dealers. Menu driven search procedures include the use of different types of keywords, names of products, manufacturers or dealers, or entire words or parts of words in the product specificitations or free text description.

A single keystroke connects the data-base to a self-developed program which allows the user to browse through the list of products he has selected during the retrieval procedure. This list is then used to indicate those devices of which an image is desired. These images with a resolution of 512 x 380 pixels and 16 gray scales are projected on a VGA computer screen. This way, less than 100 Kb is needed for storage of one image.

Preparation of the images has been executed by using a 512 x 512 pixel frame grabber with 256 gray scales. Digitized images were then corrected for irrelevant background information. A Laplace transform was applied to increase the quality of the image. At last, data reduction was performed as indicated above.

The technique has been used in two different modes, depending on the application.

For assistive devices that were not available at the dealer's or manufacturer's show room, pictures from catalogues were used. These pictures are used in a qualitative way and support the textual description in the data-base with a visual impression of the object.

A different procedure has been followed for all other products in the data-bank.
In this case, cameras were set up and calibrated (in less than 3 minutes) at the manufacturer's or dealer's place. At least 3 perspective pictures per object were taken.

Mathematical algorithms have been developed, based on linear transformations between the 3-dimensional object and the respective camera projections. These algorithms are incorporated into a software package with which user defined (with a mouse driven cursor on the screen) measurements in 3-D (height, depth, radius, size, distance, angle, ...) are derived from the calibrated pictures. Tests have shown that the accuracy of this information is better than 1%. Errors are mainly caused by limitations in the resolution of the digitized image and the computer screen.

During the development of the project, images have been stored on a tape streamer. However, the method has been designed for use with WORM disks (80% data, 20% for future updates). The total cost for hardware (micro-computer and disk drive) is in the order of 5000 US$. Textual and pixel data of 2000 products (600 Mb) can be stored onto 3 disks for less than 500 US$.

Since 160Mb erasable optical disks will become available at a low cost in the near future, some structural changes in the organisation of the data are made in order to make optimum use of the new data storage medium.

DISCUSSION

Field tests have illustrated the feasibility of the use of an image-bank that is related to a textual data-base on technical devices. At the same time they have shown that a higher quality and relevance of information could be offered, at a cost for data collection which is even lower than that in a conventional data-bank, since less effort is spent in providing descriptive information and some of the additional measurements.

ACKNOWLEDGEMENTS

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8.3

THE USE OF HYPERTEXT
IN DISTRIBUTABLE DATABASES FOR PERSONAL COMPUTERS

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ABSTRACT

In order to counter some of the difficulties currently experienced in using electronic information sources in the rehabilitation technology field, the Trace Center is currently developing distributable hypertext databases. These databases run on individual microcomputers, using new storage technologies (such as CD-ROM). They also employ hypertext software features in order to make the information easier for the average user to access.

INTRODUCTION

Difficulties in locating information about rehabilitation technology have formed a major stumbling block to its effective utilization by consumers and care providers. In attempts to combat this problem, information has been collected in various forms, including computerized databases. However, such centralized on-line information sources continue to be difficult to access, difficult to use, and expensive. One promising solution to this situation is the creation and dissemination of distributable hypertext databases. Such databases make use of new advances in microcomptuer technology to store and process much greater amounts of information at faster rates. Hypertext software, now available for microcomputers, makes it possible to write much more intuitive searching and browsing programs for users. The potential benefits of distributable hypertext databases include: lowered costs of access, faster access times, wider potential for distribution, and greater user-friendliness.

In recognition of this potential, the Trace Center is currently involved in several initiatives to create distributable hypertext databases. New databases currently in development include:

Hyper-ABLEDATA and PC-ABLEDATA: Versions of the on-line ABLEDATA assistive device database designed to run on individual microcomputers: Hyper-ABLEDATA on the Apple Macintosh, and PC-ABLEDATA on the IBM PC, PS/2 and compatibles.

Hyper-TraceBase and PC-TraceBase: Information on communication, control and computer access compiled and written at the Trace Center, also for both Macintosh and IBM computers.

Hyper Service Delivery and PC Service Delivery: A compilation of service delivery programs assembled by the EIF REC and RESNA; slated for development on both Apple and IBM platforms.

These new distributable databases combine the advantages of on-line and on-site databases. They can be updated fairly frequently; they offer quick access times and immediate printouts; they handle large amounts of data; and they offer user-friendly interfaces.

USE OF HYPERTEXT

When creating a database for use by a wide variety of people who will have minimal exposure to it, it is important that the function and operation of the database be obvious. Although nothing can be made obvious to everyone, the use of hypertext and graphic screens can greatly simplify the appearance and function of databases. Hypertext features can allow individuals to easily access items from long lists and to move around within a database, following threads of information or interest. Graphic formats can help to make screens appear simpler or more familiar, and can help the user figure out where they are within a program. (For example, when showing a listing of manufacturers' addresses, one can use a Rolodex card image, instantly suggesting to the user that they are looking at an address file.)

SERVICE DELIVERY DIRECTORY

Currently in development at the Trace Center is a hypertext directory of service delivery providers in assistive technology. For ease of use by people with little or no knowledge of computers or databases, the program was designed around a very simple visual metaphor of a book. When the database is first turned on, a picture of a service delivery directory shows up on the screen in the image of a book, along with a message telling the user to click anywhere on the book to open it (Figure 1). Clicking on the cover of the book causes it to open to a table of contents (Figure 2), which has instructions telling the user to simply click on whatever part of the outline they are interested in.

Again, hypertext allows the organization of the manual to be clearly laid out, and provides the user with a simple "point-and-click" method for accessing any of the features. Clicking on the "A. Alphabetical Listing" will cause the book to "open" to the alphabetical listings. A series of tabs down the right side provides the individual with a very familiar mechanism for accessing any portion of the alphabetical listing. For example, clicking on the "A" takes the user to a listing of the agencies whose names begin with A. They can then simply click on the name of service provider on this list in order to see a description of their services. The basic information is presented in a straightforward fashion to the individual. Additional information and detail is available by clicking on the "Other Information" box. In this fashion, a fairly large amount of information can be presented in a compact format.

When searching for information, of course, users of the database will not usually be looking for centers by name, but rather by geographical location and services provided. Clicking on this feature in the table of contents first presents a display of all of the different possible types of services catalogued in the database. The user then simply points and clicks on those services they are interested in. When finished, they click on a "Done" button, and the program takes them to a map of the United States, where they can click on all of these states they are interested in including in their search (Figure 3). If they would like to narrow their search further, they can also go to maps of individual states, where they can pick the sub-areas they are interested in, in order to locate the programs that are closest to them (Figures 4 and 5).

In this manner, a fairly involved search can be reduced to a paint-by-number procedure. Using the point-and-click method can also greatly speed up the process for generating a search, and eliminate the problems associated with failed searches due to mistyped words or commands.

ABLEDATA

Providing access to ABLEDATA is a more formidable task. The original ABLEDATA database contains 15,000 products which can be accessed using any of 4,000 keywords. The database is based on Boolean logic searching, and requires a fairly extensive training course and a commitment to master the more than 100-page thesaurus. Although this approach is the most efficient technique for practiced brokers to use when accessing the database over the phone line, the use of a personal computer, a graphic interface, and hypertext has allowed the development of an interface which can be mastered in as little as five minutes.

DISTRIBUTION

The databases developed at the Trace Center are being disseminated through CO-NET, a cooperative network consisting of information programs, professional organizations, independent living centers, service delivery programs and major clinics who provide information on rehabilitative and assistive technologies in the United States. Anyone having a copy of the database is also entitled to make a copy for anyone else. For a distribution system like CO-NET to work effectively, the user-friendly and intuitive features provided by hypertext are essential. Since the database will be distibuted widely with the minimal necessary supervision by the central source, the databases must be self-documenting and easy to operate.

Although on-line databases will continue to serve important functions in the field, it is believed that disseminable hypertext databases will change the face of information dissemination over the next five to ten years, as their unique advantages cause them to be adopted in more and more information dissemination efforts.

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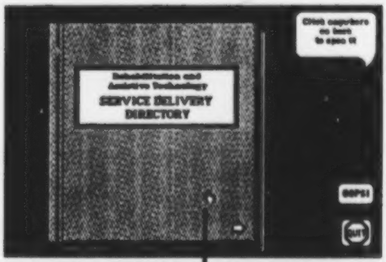
Click anywhere on book to open it
Rehabilitation and Assistive Technology
SERVICE DELIVERY DIRECTORY

Fig. 1

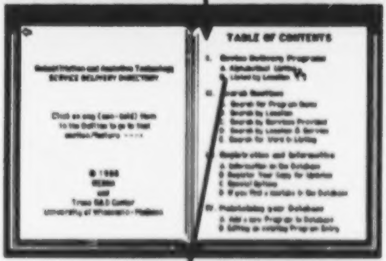

Fig. 2

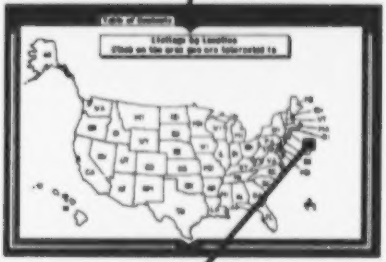

Fig. 3

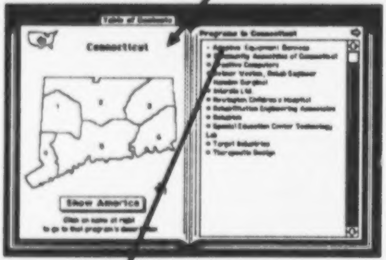

Fig. 4

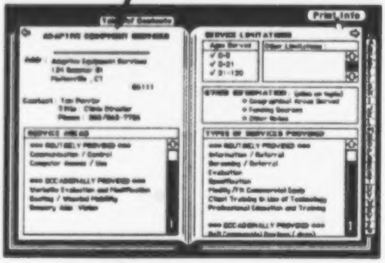

Fig. 5

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QUALITY INDICATORS FOR ASSISTIVE TECHNOLOGY SERVICE DELIVERY PROGRAMS

Shelley Kaplan, MS CCC and Pamela Harnden, MS CCC
The S.M.A.R.T. Exchange
Sharing Methods and Applications in Rehabilitation Technology

ABSTRACT

The advent of assistive technology and its application in the field of rehabilitation services has removed barriers, unmasked abilities and therefore, created new opportunities for individuals with disabilities in school, at work and in the community; however, it is not only necessary for organizations to provide these services, but that they have an overall philosophical framework which guides their growth and development. In response to the lack of available materials regarding assistive technology program practices The S.M.A.R.T. Exchange has developed a set of five quality indicators to be used as a tool for developing and/or improving existing services.

BACKGROUND

The S.M.A.R.T. Exchange seeks to improve the delivery of assistive technology services in response to the following compelling demographics:

- The population growth in the Southeastern Region is almost double that of the entire United States.
- In the areas of innovation and technology, the Southeastern Region ranks consistently at or near the bottom in expenditures.
- Federal grants are well below that of the entire nation, averaging $390 per capita in the Southeastern Region, as compared to $432 per capita for the rest of the nation.

INTRODUCTION

A set of five quality indicators has been developed and reviewed extensively by a Regional Advisory Board of distinguished professionals, parents and individuals with disabilities from Rehabilitation Services Administration Region IV. These quality indicators have provided the framework from which to select promising programs, components and practices in the field of assistive technology services. Of equal importance in the development of the quality indicators was that they serve as a tool for organizations to evaluate, develop and modify their technology-related services. Each quality indicator provides a rationale which explains its significance in addition to specific criteria which offer guidance for implementation.

DISCUSSION

The quality indicators focus on five target areas including: Philosophical Framework, Consumer/ Family Participation, Comprehensive Service Delivery Model, Funding, and Consumer Satisfaction. It should be noted that the order in which the quality indicators are presented does not reflect their importance, rather they should all be viewed as being of equal importance in the delivery of assistive technology services. The S.M.A.R.T. Exchange hopes that these quality indicators will provide the impetus for proactive organizational changes in the delivery of assistive technology services so that the needs of persons with disabilities can be more successfully addressed. The following is a brief overview of each rationale developed for each quality indicator; the complete document is available upon request:

1) PHILOSOPHICAL FRAMEWORK - The backbone to any organization is the philosophical foundation and the individuals providing the services. Organizations must demonstrate a commitment to the belief that assistive technology can enhance the lives of individuals with disabilities as well as advocate for consumer integration within the

community. It is also important that organizations not only "deliver the technology", but that they view consumers as decision-making partners in the planning, delivery and evaluation of services.

2) CONSUMER / FAMILY PARTICIPATION Consumer input in the planning, delivery and evaluation of services improves the possibility that the organization actually meets the needs of the individual with a disability. Clearly one factor in evaluating the strength of an organization is in consumer involvement during all phases of the program.

3) SERVICE DELIVERY - Even though different organizations serve distinct populations with unique economic and human resources, several common components are crucial to the success of any organization. Technology should be viewed as a means to an end and not an end in itself. To derive optimal benefit from assistive technology, organizations should structure their programs in such a manner that assistive devices and services are an integral component in all program areas.

4) FUNDING - Program staff and the consumers they serve, are often faced with frustration when seeking funding for assistive devices and services. Organizations have an obligation to guide individuals through this process to guarantee the procurement of assistive devices and services in order to enhance independence and productivity at home, school, work and in the community. Assistance in this area is therefore a necessary and instrumental service in any comprehensive organization which utilizes technology.

5. CONSUMER SATISFACTION - Organizations typically look at the issues of cost effectiveness as a measure of program effectiveness; however, consumer outcomes and satisfaction with the services provided are also primary indicators of program effectiveness. Successful organizations are consumer oriented and view consumers as invaluable partners who provide insight into the overall quality and direction of services offered. Therefore a structure must be in place to assess client satisfaction during all phases of delivery. Information obtained from consumer input should be used to modify service delivery practices on an ongoing basis.

CONCLUSION

Over the last century many new assistive devices have been developed for the marketplace, due to advances in technology, consumer demand and recently passed legislation. There has also been an increase in the number of professionals who are providing assistive technology services. In addition there is a paucity of information to guide organizations in their development of technology related services, consequently the identification of objective standards to evaluate successful programs, components and practices have been developed and hopefully, will have a significant impact on the planning, delivery and funding of assistive technology programs. Only through a widespread effort to disseminate effective practices can each program empower people with disabilities and ensure meaningful education, employment and independent living opportunities.

ACKNOWLEDGMENTS

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INDUSTRIAL DESIGN INTERNSHIP

Michelle Lynn Rekiere, student
Dr. Barry Seeger, director rehabilitation engineering

ABSTRACT

The internship at Regency Park Centre lasted eight weeks beginning may 23, 1988. During this time a selling profile, annual report, product catalogue and toilet chair were designed.

INTRO

Arizona State University requires junior industrial design students to participate in an eight-week internship. Regency Park Centre (through the department of Rehabilitation Engineering), located in South Australia, was chosen to fulfil the university requirement. Rehabilitation engineering does research and design for children with disabilities. During the internship a selling profile, annual report, product catalogue and toilet chair were designed.

METHODS

Selling profile

The selling profile was created to promote the products and services provided through rehabilitation engineering (Fig. 1). The major concern for the selling profile was to create a design that could be related to future single-product brochures. To accomplish this a few guidelines had to be determined: placement of the logo, a line for major headings, size of the border and a grid underlay for column widths. The next step was to layout the text and related photos using those guidelines. After creating a variety of layouts, the best option was chosen and prepared for printing.

Camera-ready artwork is the final form the layout will take before it can be printed. Preparing it involved typesetting the heading, photocopying computer generated text, determining the correct percentages to enlarge or reduce transparencies, photocopy any artwork and finally paste up the pieces on vellum. A series of overlays explained details of the brochure to the printer. After the camera-ready art work was finished, it was taken to different printers for estimates, and a printer was chosen for the job. The Selling Profile was printed on glossy paper.

Annual Report

The annual report (Fig. 2) was developed using the same guidelines and process as the selling profile. The main objective for the annual report cover was to design a cover that would keep a consistent look, yet could have changes made for the next year without changing the layout. To accomplish this, the layout was designed to have fixed features and changeable features. The fixed features are the logo, title, and the placement of photos, the year and the splash of color. The changeable features are the subject matter of the photos and the number of the year.

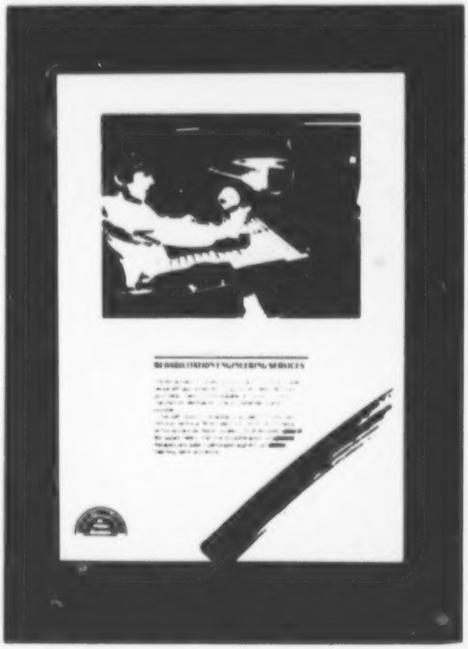

Figure 1 Selling Profile

INDUSTRIAL DESIGN INTERNSHIP

Figure 2 Product Catalogue and Annual Report

Product Catalogue
The product catalogue cover (Fig. 2) is based on the format of the annual report cover. The difference between them is title, content of the photos and color of the cover. The layout of the inside information was based on the cover by the use of three columns, placement of photos and title line. Camera ready art-work was produced for each cover and printed at Regency Park Centre.

Toilet chair
The toilet chair design for Julia Farr Centre (Fig. 3) was for a group of severely disabled young adults with cerebral palsy who were unable to sit on a toilet using any commercially available support. The first step to designing the chair was meeting with the client and gathering information about what features the toilet chair was to have. The features included adjustments for attendants such as seat angle, back rest, leg angle and foot plate height. The chair was required to be easy to operate, be mobile using locking casters, easy to clean, and durable. To obtain the range needed for the adjustments, measurements were taken of the users. The measurements were analyzed and ranges for the adjustments obtained. The next step was to generate a functional and clean design to present to Julia Farr Center. A final sketch was presented and discussed.

SUMMARY

At the end of the eight week internship, the selling profile was in the process of being printed, the annual report and product catalogue covers were printed and the centre was waiting on a decision from Julia Farr Centre regarding the toilet chair. Subsequently, the selling profile, annual report and product catalogue have been printed and distributed throughout Australia and overseas. The toilet chair design and quotation were accepted by the clients and it is now being manufactured.

The internship left me with a feeling of hope towards issues related to disability. To see the children wearing and/or using their equipment proved this field is necessary. The experience I received at Regency Park Centre made me realize the need for research and design in this area. After I graduate, May 1989, I want to use my talents to design towards issues related to disability.

ACKNOWLEDGMENTS

Dr. Barry Seeger, Director Rehabilitation engineering, Regency Park Centre, South Australia.

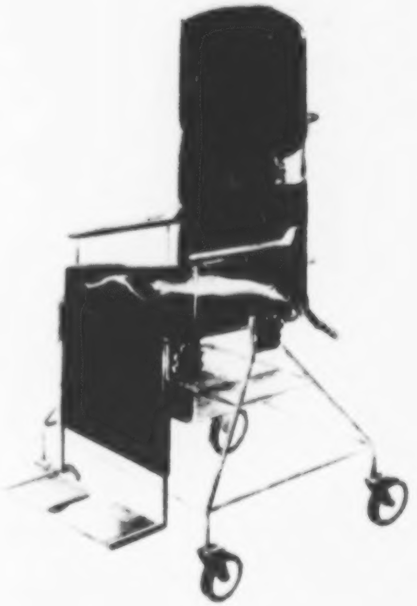

Figure 3 Toilet Chair

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STATE OF THE ART IN 1988 ON UNIVERSITY CAMPUSES

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ABSTRACT

The purpose of the study was to collect demographic data regarding disabled students enrolled in university programs in 1988. A survey design was utilized to sample directors of college disabled student services programs. The response rate was 61 percent. The results and discussion summarize the data regarding: disabling conditions represented, professional services available, augmentative and alternative communication techniques utilized, and ages and numbers of severely-handicapped students on college campuses in 1988. A plan for more appropriate service delivery in the 1990's is outlined.

INTRODUCTION

With Public Law 94-142, children with handicaps have been receiving services in the public schools in grades K-12. Currently, many of these children are students entering their junior and high school years. Historically, these students have had few opportunities to advance towards enrollment in higher education. The purpose of this research was to develop a plan for a future in which students with increasingly severe disabilities may attend university programs. Specifically, the objective of the study was to collect demographic data regarding the current numbers of disabled students with specific handicapping conditions who were enrolled in university programs in 1988.

METHODS

In order to accomplish the objective of the study, a survey design was selected. Two and four year colleges listed in A Guide to Colleges for Mobility Impaired Students (1) comprised the population for the study. Specifically, 150 disabled student services programs were randomly selected from approximately 600 facilities listed (1). A mail survey was conducted sampling programs across 41 states.

The mailed survey questionnaire included 14 questions, accompanied by a cover letter addressed to the director of each college disabled student services program. The questions were designed to collect data regarding the following: disabling conditions represented in the student body; average age of disabled students on campuses; professional services available on campuses; number of students receiving augmentative and alternative communication (AAC) services; number of students on campuses with mobility impairments; number of students needing adapted computer access for writing; and a breakdown (by type and number) of methods/techniques used for communication (spoken or written) by AAC users on campuses.

RESULTS

The response rate to the survey was 61 percent (92 questionnaires). The results of the survey indicate the following:
1. The disabiling conditions most frequently represented in the study body of colleges include cerebral palsy, multiple sclerosis, closed head injury, muscular dystrophy, and reported shock/trauma/surgery. 2. The professional services most frequently available to disabled students include counseling, vocational rehabilitation, speech-language pathology, physical therapy, and social services. 3. Forty-nine percent of the colleges reported seven or fewer AAC users on campus, and seven or fewer severely physically handicapped students, requiring adopted computer access.
4. Sign languages or gestures were the most frequently used AAC techniques, followed by electronic devices.

DISCUSSION

The information collected provides a preliminary data base from which preparations may be made for training practitioners in the health sciences fields, and faculty on university campuses to identify potential social, academic, physical, vocational, and/or communication barriers on their own college campuses. Specifically, the survey identified services available for AAC users on campuses in 1988. This paper presents a plan for more appropriate provision of services on college campuses in the 1990's.

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SENTENCE RECOGNITION FOR AUDITORY AND VISUAL SCANNING TECHNIQUES IN ELECTRONIC AUGMENTATIVE COMMUNICATION DEVICES

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ABSTRACT

This research examined whether recognition of messages in scanning devices is affected by the different presentation modalities and quality of auditory presentation. An electronic Augmentative Communication device that presents whole messages serially with visual, auditory, and auditory-visual scanning techniques was computer simulated. 96 subjects were asked to remember targets in the 3 modalities and take sentence recognition tests after each condition. Response accuracy was highest for visual and auditory-visual scanning and lowest for auditory scanning presentations. Reaction times showed visual scanning was fastest, auditory scanning was slowest and auditory-visual scanning fell between the two. Intelligibility for auditory scanning is best for DECtalk, then Votrax PSS and lastly the Echo PC systems.

BACKGROUND

One goal of R&D for Augmentative Communication is to make the interaction between electronic devices and device users as efficient and effective as possible. Since the user must form an association between the available messages in a device and his/her communication needs, the comprehensibility of the message presentation in AC devices is crucial. Indeed, the manner of presentation or the machine's information display affects how well the user learns to use a device.

In electronic scanning devices, there are 3 options for information presentation. Messages are displayed serially through the visual modality, the auditory modality or combined visual-auditory modalities.

This research examined whether there is a difference in message recognition for visual, auditory, or combined visual-auditory scanning presentations. A second goal was to quantify the influence of speech synthesis intelligibility on messsage recognition in auditory scanning devices. In other words, this project examined how the interaction between the device user and the electronic device was affected by different modalities and quality of message presentation.

METHODS

Subjects

96 adults between the ages of 18 to 65 served as subjects. Volunteers had within normal or corrected vision and hearing.

Equipment

Equipment included an IBM XT/PC with monochrome monitor, a switch interface connected to 2 tread switches, and 3 speech synthesizers. Software was designed to simulate a scanning device within the 3 modalities; to present recognition tasks; and to tally all responses for analysis.

The three speech synthesizers were: DECtalk with Perfect Paul, the device's standard male voice; the Votrax Personal Speech System with words entered using standard English spelling; and the Echo PC using standard English spelling.

Stimuli

Target stimuli included 120 sentences, divided into 3 sets. Each sentence had 5-7 syllables (2). Content included frequently used vocabulary of AAC device users (1), and words common to adult patients in the rehabilitation setting. Three sentence recognition tests with 120 stimuli each (40 targets and 80 foils) also were used.

Procedure

Subjects were presented with 3 different sets of messages and subsequent sentence recognition tests. One set of messages was presented visually: seen on the monitor only; 1 set through the auditory modality: heard through a speech synthesizer only; and a third set in the visual and auditory domain: seen on the monitor and heard through the synthesizer simultaneously.

Subjects saw and/or heard 40 messages in a set. They were told that they would take a sentence recognition test immediately following the message presentation. They were instructed to hit a "yes" switch if they had seen and/or heard the message previously, or a "no" switch if messages were unfamiliar.

The placement of the different message sets in the three conditions, the order of the messages in each condition, and the order of modality presentation were pseudorandomized and balanced across subjects.

RESULTS

Three Modality Conditions

Response accuracy. The first table presents average percent correct responses for the 3 modality conditions. Messages presented visually had the highest recognition scores. There was no significant difference between average percentage of correct responses for the visual and auditory-visual presentations. The auditory only presentation produced significantly more errors in recognition.

Percentage Correct Responses on Sentence Recognition Tests in Three Modalities

	Visual	Aud	Aud/Vis
Minimum %correct	15	0	20
Maximum %correct	100	100	100
Mean %correct	80.97	78.32	83.04
Standard Deviation	16.71	17.33	14.47

Reaction time (RT). The time between the stimulus beginning and the switch closure constitutes reaction time. RTs for the three modality presentations are displayed in the next table. The auditory condition had the longest mean RT; the visual condition had the shortest RT, and the visual-auditory condition fell between the two.

Reaction Times (In Seconds) for Sentence Recognition Tests in Three Modalities

	Vis	Aud	Aud/Vis
Minimum RT	.51	1.70	.55
Maximum RT	4.81	5.53	3.61
Mean RT	1.31	3.07	1.63
Standard Deviation	.54	1.63	.61

Speech synthesis intelligibility

Response accuracy. The following table displays percentages of correct responses for sentence recognition tests with the 3 speech synthesizers. As expected, DECtalk presentation produced the best scores, followed by the Votrax PSS and Echo PC.

Percentage Correct Responses on Sentence Recognition Tests with 3 Speech Synthesizers

	DECtalk	Echo PC	Votrax PSS
Minimum %correct	0	35	20
Maximum %correct	100	100	100
Mean %correct	82.23	78.93	80.89
Standard Deviation	5.47	16.20	16.47

Reaction time (RT). The final table shows the RT data for recognition tests using the 3 speech synthesizers. RTs for the DECtalk system were the lowest, with the smallest range and standard deviation. It is interesting to note here that the Echo PC produced slightly shorter RTs than the Votrax PSS.

Reaction Times (In Seconds) for Sentence Recognition Tests with Three Speech Synthesizers

	DECtalk	Echo PC	Votrax PSS
Minimum RT	.65	.55	.74
Maximum RT	4.61	4.29	5.53
Mean RT	2.13	2.16	2.49
Standard Deviation	.79	.89	1.07

DISCUSSION

Effective use of AAC devices that present messages serially presupposes that users know all message options. Message recognition is the first step needed to learn the device content. This study proved that message recognition is best accomplished when messages are presented visually. The addition of an auditory component may slow down performance for able-bodied adult learners, but doesn't decrease accuracy. Caution must be taken for learning messages with an auditory scanner only, however, since results showed least efficient and poorest performance with this single technique.

The dynamic versus static nature of information processing may play a role in the results. Visual scanning has a static component, that is to say that the targets appear on a screen as a whole unit for a given time period. Auditory information, on the other hand, is dynamic in nature. Uninterrupted auditory attention is required to quickly process the temporary information presentation and choose a message.

Results of synthetic speech intelligibility on message recognition in auditory scanning devices is consonant with results obtained on word/sentence identification tasks (3). In that study, phrasing is recommended over single words for messages in AAC devices. This study further suggests that added visual cues for scanning devices greatly increases recognition rate and accuracy.

ACKNOWLEDGMENTS

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A PROTOTYPE CONVERSATIONAL PROSTHESIS FOR SEVERELY DISABLED NON-SPEAKING CHILDREN

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ABSTRACT

This paper describes the development of a conversational prosthesis for severely disabled non-speaking children. The prototype will be constructed using HyperCard software on a Macintosh SE. The system will be based on language development research and will be designed for usage both as a learning environment and as an output device for real-time conversations.

MOTIVATION FOR RESEARCH

A prototype conversational system for disabled child non-speakers is being developed on a Macintosh SE using HyperCard software and the HyperTalk proramming language at the Microcomputer Centre at the University of Dundee, Scotland UK. The predecessor for this system is the CHAT system (Conversation Helped by Automatic Talk) which is a research prototype of a speech communicaton system for severely disabled adult non-speakers [1].

Although non-speaking children undergo a language development process, until now there has not been a systematic approach toward computationally modelling the child's abilities within the communication aid itself [2]. Unfortunately, the field of language acquisition and development for severely disabled non-speakers is greatly under-researched. It is felt, however, that the literature of child language acquisition can provide an important input for research and development of a computer-aided conversational prosthesis for non-speaking children because the field of development and acquisition of language for unimpaired speakers is well established.

HYPERMEDIA MODULES

This communication aid described in this paper is designed as a hypermedia system which takes into account the child's semantic, syntactic and pragmatic knowledge. (The data for these components will in the first instance come from the child's speech therapist who will have made various diagnostic analyses of the child's language acquisition and communicative behaviour.) The goal is to present the child's own knowledge to him/her in the optimal format for its use and expansion. Guidelines for formatting knowledge are being sought from child language development literature. For example, for two-word utterances (which may be expressed by the non-speaking child as sounds, gestures, or pointing with a low-technology communication aid such as a Bliss board) different types of 'meaning relationships' [3] are expected to be found. (Brown's list of 'meaning relationships' includes eight 'minimal two-term relations', and three 'basic operations of reference', examples of which are [3, p. 125].

RELATIONS:
1. ***Agent action*** : **MOMMY PUSH**
2. ***Action and location*** : **PLAY GARDEN**

REFERENCE:
1. ***Recurrence*** : **MORE MILK**
2. ***Non-existence*** : **ALLGONE EGG**

Modules included in the basic system are: 1. Lexical database: each lexical item is stored as either a drawing or a scanned photograph. 2. Syntactic database. This contains syntatic templates for varying syntactic skill levels. E.g., in the case of two-word utterances these would take the form of a 'meaning relationship' noted above. 3. Conversational database. Conversation templates will be originally extracted from the child's own conversations as recorded by the speech therapist. New conversational skills will be introduced through the generation of conversations in which situations, participants and utterances will be manipulable by the speech therapist or the child. Different and more advanced conversation templates will be devised from research about turn-taking and speech act usage for both unimpaired and impaired children, examples of which are: 1. Kraat and Potter have examined the use of speech acts by aided non-speaking children [4]; 2. Jose has experimentally elicited taxonomies of speech act categories for unimpaired young children [5], and 3. Keenan and Klein have studied how children "use language in concrete situations" [6, p. 379]. In addition to the three main modules, a range of input and navigational devices specific to a variety of disabilities will be simulated (e.g., touch-activated buttons, mouse-operated buttons, switch-activated buttons).

LEARNING AND OUTPUT

The design outlined above should help to overcome several intrinsic problems associated with the use of communication aids which are based only on pointing to selected words or concepts. Flexibility will be gained from the ability to build conversational components from lexical items, syntatic templates and conversation templates. The result will be *both*: 1. The realisation of conversation simulations that can be manually or computationally generated and played back through speech synthesis software, and 2. The generation of customised utterances for use in real conversations. Thus, the 'conversational aid' will be useable either as a ***learning*** environment or as an ***output device*** for participating in conversations.

METHODOLOGY

The development cycle of this conversational prosthesis for children will include interactive sessions between the speech therapist, the child user and the HyperCard/HyperTalk programmer. This will ensure that each user is able and willing to use the modules provided both for learning about and for participating in conversations. The flexibility gained from linking, generating and customising conversational components should greatly improve the non-speaking child's conversational performance.

ACKNOWLEDGEMENTS

This work is funded by a grant from the Spastics Society.

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A Preliminary Design of an Educational System for Use with the Eye-Gaze Interface Computer Aid

9.4

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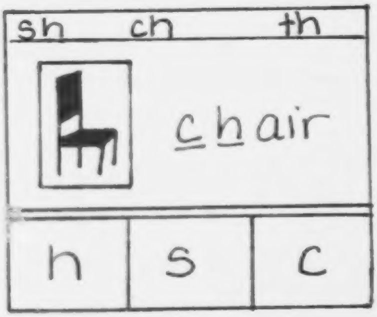
The Eye-Gaze Computer Aid is an augmentative communication device which uses eye-gaze as its form of input. One component of ERICA is its educational system which allows emulation of workbooks and other teaching materials.

ERICA, the Eye-Gaze Interface Computer Aid, is an augmentative communication device for the handicapped which uses eye-gaze as its form of input. With the help of an AT computer, imaging board, surveillance camera, and an infrared light emitting diode, it is possible to determine where a person is looking (1). An educational system is one of the four components of ERICA, communication, personal needs, and games being the others.

The educational system is broken into configurable and nonconfigurable sections. The former allows the construction of menu screens which can emulate workbooks and other classroom materials, while the latter consists of a number of set programs dealing with the alphabet, spatial relationships, counting, and sequencing. Each configurable progam is accompanied by a separate setup program which allows the instructor to shape the exercises. Unlike the eye-gaze driven user programs,input to the setup program is entirely through the keyboard.

In the lower grades reading is taught through the use of the blends. A blend is picked, e.g. 'at', and the related words are explored. ERICA reinforces this process with two configurable programs. The first uses a 3X3 matrix formation of boxes. The blend resides in the middle box, surrounded by eight boxes each containing a letter, which may or may not make a word when combined with the blend. An example menu might have 'at' in the middle box, surrounded by the letters b, c, v, n, m, f, h, k, allowing six possible words. If the user selects a letter that makes a valid word a smiling face appears and the word is simultaneously spelled out on the screen and spoken by a voice synthesizer for visual and aural reinforcement. After a pre-set number of iterations, the correct word list is displayed and the voice synthesizer reads the list in review.

The second blend program examines related word lists. The instructor, through the setup program, enters in the set of words that he wishes to use. There are three different screen formats to chose from, one is illustrated in the diagram below.



Each menu corresponds to a single word, for which four parameters must be input. The first is the list of the examples across the top to which the student may refer. The second is the visual aid. Any picture desired may be used simply by drawing it with black magic marker on a large index card and capturing it with the camera. Next, the word is marked to delineate the part to be highlighted. Lastly, the instructor decides what is to be put in the choice boxes and indicates in what order they must be selected. Once again there is positive reinforcement of a correct choice followed by its enunciation by the voice synthesizer.

The nonconfigurable section of the educational system reviews the alphabet, sequencing, counting, and spatial relationships. Color graphics and musical feedback are used for enhancement. The educational graphics are based on 26 pictures, each one corresponding to a letter of the alphabet.

The alphabet program displays a sequence of four graphic elements and three of the corresponding letters. In place of the fourth letter is a blank. The student then must decide, with the aid of the picture, which letter to choose from the four choice boxes. Sequencing is also done with numbers. Four digits and their corresponding labels are shown across the top of the screen. After a short amount of time one of the words and its digit are erased and the student must choose the correct one from the six choice boxes. Numbers are also used in a counting game which matches a group of graphic elements with the correct number. In this case the corresponding digits are not used, reinforcing the words.

Spatial relationships are explored in the final program. The top of the screen has a rectangular colored region with a black shape on it, indicating that a colored shape has been removed from the rectangle. Below are two choice boxes, one of them containing the shape that would complete the above colored rectangle, one with an incorrect choice. The user must choose between the two. The program uses five shapes: a circle, triangle, square, rectangle, and lightning bolt. Variables include shape, color,and size, giving a large subset of possible choices.

Testing of the programs is currently being conducted in Oklahoma and Charlottesville. The subjects are all children ranging from the first to the third grade levels. Preliminary results show that interesting and colorful graphics as well as musical reinforcement play a large factor in the system's success.

This research was funded through a grant from the Virginia Center for Innovative Technology with additional support from NYNEX and the IBM Corporation. The Oklahoma City Public Schools and The Bloomfield Home have also donated a large amount of time to make this research possible.

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MATERIAL PROPERTIES OF SOFT TISSUE IN COMPRESSION

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INTRODUCTION

Decubitus ulcers are a major concern among people who use wheelchairs. The most significant factor in the etiology of these ulcers is the pressure which acts on the soft tissue. This pressure occurs as the tissue is squeezed between the pelvic bones and the wheelchair cushion. Computer methods may be used to determine the pressure distribution within the pelvic region. One method of analyzing this problem is to treat the soft tissue as a composite material made from skin, muscle, fat, and vascular and lymphatic vessels. The material properties of this composite tissue may be determined from force-deflection curves. It would be beneficial to develop a generic set of properties for different body types. In this paper, force-deflection curves for different test subjects are compared. The linearity and time dependent effects are noted as well as the effects of gender, body type, and anatomical location.

BACKGROUND

In the biomechanics literature, soft tissue is described as being a non-linear, anisotropic viscoelastic material.[1] Investigations of the properties of tissue have often been made by placing in vitro strips of tissue in uni-axial tension.[1] Study of the components of tissue reveals that differences are likely to exist under in vivo compressive conditions.[2] Tissues consist of fibrous components which uncoil before they stretch in tension. In the presence of body fluids, these fibers will not act in the same way in compression.

METHODS

Methods used in this work are based on those in a similar study that examined the pressures caused by a lower limb prosthesis on a residual stump.[3] In that work, a socket containing seven holes was designed for a below-knee amputee. A plunger device was inserted into each of the holes in turn, and the correlation between force and tissue deflection was recorded.

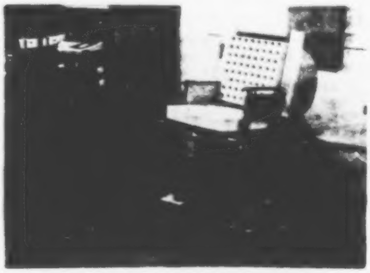

Figure 1. Adjustable Fitting and Positioning Seating System

At the UVA-REC, an instrumented, adjustable fitting and positioning seat system (Figure 1) was developed to study pressure distribution at the body-cushion interface.[4] This seating system contains several of the features of the socket previously described: there is an array of holes in the seat through which an indentor may be placed to measure force and tissue deflection.

The contour gage seating system was used to make contour cushions for two young adult male and two young adult female test subjects. A two-inch diameter hole was cut from the cushion under the right ischial tuberosity. A pressure pad from an Oxford pressure monitor was mounted on one of the indentors in the adjustable seat system. With the subject seated on the cushion, the indentor was pushed through the hole against the free-hanging tissue. The indentor was raised in one millimeter increments, and the corresponding surface pressure was recorded. Corresponding forces were calculated from the pressure data.

Similar measurements were made for an area under the right thigh of one of the male and one of the female subjects.

RESULTS

The following generalizations can be made from the force-deflection curves in Figures 2-4.

—The shape of the curves is non-linear with a gently increasing slope.

—The slope of the curve for the tissue under the buttocks is greater than for that under the thigh as shown in Figure 3.

—For both the buttocks and thigh, the slope of the curves is greater for the male subjects than for the female subjects as shown in Figures 2 and 4.

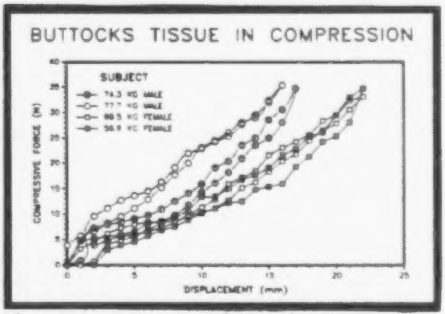

Figure 2. Buttocks Tissue in Compression

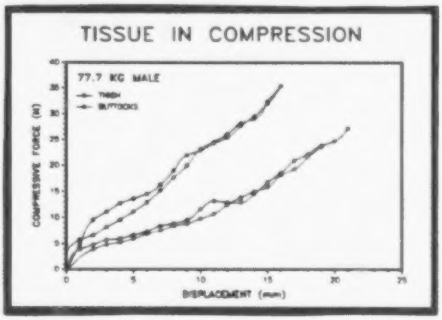

Figure 3. Buttocks and Thigh Tissue in Compression

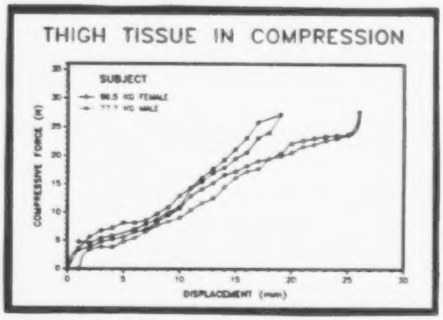

Figure 4. Thigh Tissue in Compression

—Hysteresis exists in all of the curves.

DISCUSSION

The non-linearity of the force-deflection curve was not as great as expected. Additionally a larger amount of tissue deflection was produced than expected, so it was realized that the indentor was deforming along with the tissue. A small portion of the indentor underneath the pressure pad was made from a nonlinear foam material. As the tissue was compressed, the indentor deflection was included in the displacement measurement.

One of the characteristics of viscoelasticity is hysteresis as shown in all of the data. Any computer model of soft tissue should address these time-dependent effects.

The slope and size of the force-deflection curves are dependent upon the test subject's body-build and gender. Different body builds contain different amounts of tissue components, each having different material properties. Unless large databases are formed for each body type, it will be difficult to generate a generic model containing generic material properties. Until then, properties for the individuals being studied will have to be used.

CONCLUSIONS

In generating computer models of soft tissue in the buttocks, it would be beneficial to be able to use generic material properties for a certain type of subject. From the force-deflection curves determined from test subjects of similar body types, it was found that there are differences in the slope and size of the curves. Presently, when generating computer models of soft tissue, individual force-deflection curves should be generated.

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SKIN TEMPERATURE AND ERYTHEMA AFTER PROLONGED SITTING IN SPINAL CORD INJURED INDIVIDUALS

11.2

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INTRODUCTION

The need to develop better indicators and improved interventions for pressure sore prevention is well established. An important aspect of this need is the requirement for more quantitative tools to assess the damage produced from external loads on human tissue. A common clinical indicator used in the assessment of skin of the load bearing surfaces of wheelchair users is erythema (skin redness). Both the size of the involved area as well as severity are important parameters in considering erythema. A more quantifiable measure which has been used experimentally is temperature.

This paper describes a study where both erythema and temperature are measured in spinal cord injured subjects seated for 1-4 hours without pressure relief. The purpose of this research is to quantify changes in these parameters over time and develop a relationship between surface temperature and tissue damage as measured by erythema.

REVIEW

Several studies have investigated the thermal response of tissue subjected to localized pressure. Mahanty et al.[1] noted a transitory skin temperature response at a pressure application area which increased to a maximum within 2-5 minutes after the release of pressure. Magnitude and duration of pressure were used as the independent variables in this study. The experimental design did not include skin inspection for erythema. Patterson and Fisher[2] studied pressure and temperature patterns in wheelchair users through a normal day's activities. Thermography has also been used to monitor pressure sore healing[3].

Skin temperature may also play a causative role in the formation of pressure sores. Tissue cooling can promote vasoconstriction and tissue ischemia, and perhaps facilitate pressure sore development. High temperature may contribute to cellular metabolic deficiencies by increasing metabolic rate and hence tissue demand for oxygen. Both of these conditions can potentially be exacerbated when blood supply is already compromised as a consequence of external loading and tissue deformation.

In order to utilize both erythema and temperature quantitatively it is important to establish the relationship between them. The experimental results presented here will be used to analyze this relationship under the circumstance where prolonged erythema is produced as a consequence of sitting without pressure relief. To our knowledge, no previous investigation has been reported where skin temperature and erythema intensity and duration after tissue damage have been concomitantly measured.

The experimental design and results reported here are part of a larger study where erythema and temperature are being employed to quantitatively assess the effects of electrical muscle stimulation for pressure sore prevention. Results of these trials are incomplete and will be reported at a later date.

METHODS

Four spinal cord injured inpatients have been studied to date. All subjects must have a complete (or incomplete with minimal sensory/motor function) spinal cord lesion at the cervical or thoracic level and less than six months duration since the time of their injury.

A "Critical Sitting Time (CST)" is established before any temperature measurements are made . This is defined as the first sitting time at which erythema (skin redness) persists for one hour after pressure relief. This one hour period was empirically chosen based on clinical experiences with spinal cord injured patients. The purpose of the CST is to induce prolonged erythema which is reflective of more than reactive hyperemia, but can be reversed with a maximum of 24 hour rest. (Reactive hyperemia refers to the phenomenon of vasodilitation and short term increases in blood flow following an incidence of occlusion).

CST determination begins with a trial seating session of 30 minutes. The subject is not allowed to have any pressure relief while sitting in the wheelchair during a session. There is a minimum 24 hour period between any two test sessions to ensure adequate tissue recovery time. A vinyl covered 2-inch layer of high density foam over plywood is provided. (This type of cushion is intended to provide only a moderately compliant seating surface). The skin over the ischial tuberosities and other buttock tissue is visually inspected and rated on a predetermined 1-10 scale. Inspection is performed immediately after transfer of the subject to bed following a trial session. The visual inspection is repeated one hour later to ascertain whether the erythema still persists. Sitting duration is increased with each session by 1/2 hour increments until erythema persists for 1 hour. The CST is established when this result is repeated in two consecutive trials.

Trial sessions with quantitative measurement of erythema and temperature begin with subjects sitting without pressure relief for the CST. At the conclusion of this CST session, each side of the buttocks is visually graded on the 1-10 scale and the maximum and minimum diameters (a&b) of the erythematous area over the ischial tuberosity is measured bilaterally by hand. The area is then calculated as $1/4\,\pi ab$.

Immediately after these measurements, a central temperature probe is affixed on one side over the site of highest intensity erythema (usually corresponding to the area over the ischial tuberosity), with four other probes radially placed at a distance of 6 cm. This method is a modification of that described by Mahanty et al.[1]. Temperature readings are recorded on-line by computer for one hour. Differential, T_D, is used as the key parameter and calculated by:

$$T_D = T_C - T_{1\text{-}4},$$

where T_C equals the temperature at the center of the erythema area and $T_{1\text{-}4}$ equals the average temperature of the other four surrounding probes.

These trials are part of a larger study investigating electrical muscle stimulation for pressure sore prevention, where 4 CST trials are performed, 2 with stimulation and 2 without. Results reported here are only for the two trials without stimulation. (Outcomes regarding electrical muscle stimulation efficacy require completion of the experimental protocol with a larger number of subjects before any conclusions can be drawn).

RESULTS

Erythema Duration and Intensity. The size of the erythematous buttock area decreased in all subjects between the first inspection immediately after pressure relief and the second inspection one hour later. The range of the area decrease varied from a 46% to 100%. The intensity of the erythema also decreased by 1 to 4 units on the predetermined 1-10 scale between the two inspections.

Temperature. Differential temperatures are plotted against time in Figure 1. A distinct and consistent pattern of differential temperature has been obtained with the subjects tested so far. The temperature starts at an elevated level and declines (though not to zero) over approximately 20 minutes. The minimum T_D obtained remained above 0° during the entire hour for 3 of the 4 subjects.

Correlation Between Erythema and Temperature. The size and intensity of the erythematous area initially and at one hour after the CST are plotted against T_D in Figure 2. The graphical analysis indicates that there is a consistent relationship between the reduction in erythema and the decrease in T_D. Until a larger number of subjects are studied, statistical analyses cannot be performed.

DISCUSSION

It is difficult to establish the relationship between an indicator of tissue damage used in seating assessment and pressure sore formation. This is due to the fact that the incidence rate of pressure sores and the length of time involved make it very difficult to perform general population studies. Previous investigators have looked indirectly at the relationship between temperature and tissue damage by relating temperature with the magnitude and duration of external load. This study's experimental procedure measures temperature under circumstances which approximate the actual situation leading to pressure sore formation in spinal cord injured individuals. Additionally, intensity and duration of erythema are used as measures of tissue damage and compared with temperature.

A notable finding was the length of time that T_D remained elevated (it did not return to baseline even after one hour in three of four subjects). Measurement of T_D in subjects prior to a CST trial indicate that it is very close to 0° after prolonged rest. The implication is that tissue effects are occurring beyond an hour as a consequence of the CST trial. It is also interesting to note that in 3 of the 4 subjects T_D appears to reach a minimum and then level off or even rise a small amount over the hour following the CST trial. This leads to the hypothesis that there may be long term mechanisms, distinct from initial reactive hyperemia, effecting change within the tissue.

This preliminary research extends previous work on temperature as a quantitative measure of tissue damage resulting from external load. Correlation of erythema and temperature should help further clinical applications of temperature measurements and assist in developing more quantifiable assessment methods.

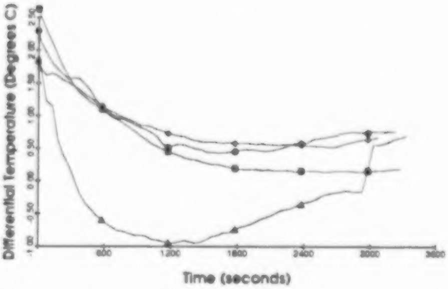

Figure 1: Differential temperature vs. time After CST from 4 trials with different subjects.

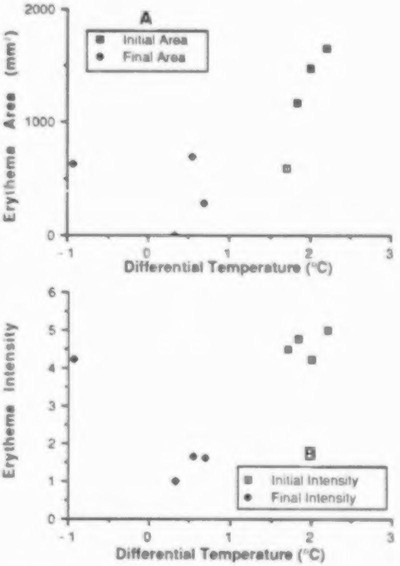

Figure 2: Area (A) and Intensity (B) of Erythema

ACKNOWLEDGEMENTS

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THE EFFECT OF POSTURAL STRESS ON LOWER LIMB BLOOD FLOW IN SCI PERSONS

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ABSTRACT An impedance plethysmograph unit has been interfaced with a computer to form a versatile method to monitor limb hemodynamics. Relations between lower leg blood flow and postural changes in spinal man were investigated. Flow to the calf was reduced by 40% after changing the body position from supine to reclined. Tilt in-creased flow in non-SCI subjects, but had little effect on a C7 level SCI subject.

INTRODUCTION

Maintaining a seated posture for long periods of time affects virtually every system of the body, including the circulatory, renal, endocrine and nervous systems. Many responses are due to the pooling of blood and fluids in the lower limbs. Spinal cord injured (SCI) persons are at greater risk of venous pooling because they 1) maintain a dependent position (seated) for long durations, 2) have limited or no lower extremity muscle activity to aid venous return and 3) may have reduced vasomotor responses due to their spinal cord lesions. Some studies have measured calf blood flow and limb volume changes with respect to postural stress (1,2) but data specific to SCI persons is quite limited. Problems associated with lower limb circulation in SCI persons include limb edema, deep venous thrombosis and decreased blood flow to the tissues in the shank and foot

The objective of this study was to determine the characteristics of blood flow in the lower limbs of SCI persons while in a seated position. These characteristics include the response to changes in body position and orientation. Ultimately the knowledge obtained may aid in the development of clinical guidelines for wheelchair users. Maximizing microcirculatory blood flow should reduce the risks associated with decreased flow and edema in the lower extremities.

INSTRUMENTATION

All measurements were made with an impedance plethysmograph (3). Two electrodes, which constitute a constant current source, are taped around the circumference of one leg 5 cm above the ankle and 5 cm below the knee. Between these, spaced 18 cm apart, are two more electrodes which act as a voltmeter. As blood volume increases in the leg the electrical impedance and voltage decrease proportionally. The output of the machine, DZ, which changes periodically with the pulse, is multiplied by a constant to represent a change in volume. Also available is the derivative of DZ, DZ/DT. The signals are conditioned by analogue filters, whose cut-off frequencies were determined by Fourier analysis and collected using a computer equipped with an A\D converter. Flow values are calculated from equations developed by Kubicek (3).

METHODS

Six subjects, 5 able-bodied and 1 SCI, were included in this preliminary study. Subjects were seated on a powered tilt/recliner unit which enabled the evaluator to alter body position quickly and accurately. Changes in position were defined as changes in seat-to-back angle and knee flexion angles and were achieved by using the reclining feature of the unit. Three body positions were used and included supine (back: 0 deg, knee flexion : 15 deg), reclined (back: 30 deg, knee flexion: 40 deg) and a nearly upright seated posture (back: 75 deg, knee flexion: 85 deg). Body orientation changes were accomplished by the tilt feature of the unit. The upright position was fixed while the entire body was tilted in space by varying the seat-to-horizontal angle from 0 to 30 degrees in a 15 degree increment.

Blood flow was measured during 4 samples at each position. Each sample consisted of 4 to 5 pulses of DZ and DZ/DT. Data was stored on disk for subsequent evaluation. Flow in units of cc/minute was calculated by multiplying volume per heart beat by the heart rate. Flow measurements were taken 15 minutes after a position change. The adjustment period allowed adequate time for the acute tissue blood flow control mechanisms and the short term nervous and humoral pressure regulators to react.

RESULTS

Flow values were normalized to the supine position of each subject so that only relative changes in flow were analyzed. Data from the SCI and one non-SCI subject are reported. Plots of normalized flow versus body position and orientation are contained in Figures 1 and 2.

In both cases blood flow was greatest in the supine position. After raising the back and legs to the reclined position, blood flow dropped to 61 and 60 percent of the supine rates of the SCI and non-SCI subjects, respectively. After assuming the upright posture, the flow dropped further to 57% for the normal subject but remained at 61% for the SCI subject.

During tilting of the seat to 15 and 30 degrees, blood flow of the SCI subject remained nearly constant at 61 and 62 %. After a similar tilt, the non-SCI subject experienced an increase in flow from 57% (upright) to 66 and 71 % at 15 and 30 degrees respectively.

DISCUSSION

During recline of both subjects, blood flow through the lower limb was sharply reduced during the first 30 degree increase in the back angle and thereafter was regulated at a constant rate. More points on the flow vs. recline curve are needed to determine more precisely the flow relations between the supine and recline positions.

The increase in flow after a 30 degree tilt was over 10% in the limb of the normal subject. The quadriplegic, however, did not respond at all. The lack of a response to the change in orientation may result from the loss of this subject's sympathetic tone because of a cervical lesion. Tilting is a potential temporary alternative to the upright position because of increased blood flow. Other subjects with lower lesions may respond to the tilt.

Long term changes in the years since injury, occurred from the loss of the sympathetic autonomic system which normally reacts quickly. The vessels have lost vasomotor tone causing the arteries to lose resiliency, and the veins no longer resist blood pooling. In general, the cardiovascular system has become insensitive to postural changes.

Further experiments should include subjects with varying levels of SCI in order to relate these levels to limb hemodynamics. The term hemodynamics is used to stress the fact that besides measuring blood flow, limb volume changes of the leg between each position are being studied. Also, inspection of the impedance pulse wave can reveal arterial obstruction, impeded venous emptying or other differences between the SCI and non-SCI groups.

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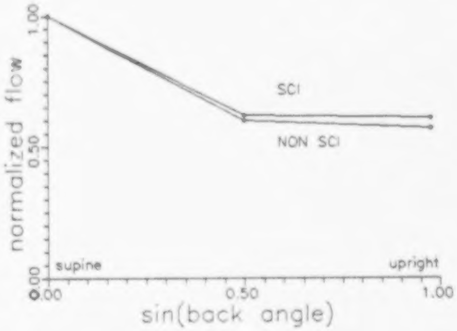

Figure 1. Blood Flow vs. Recline

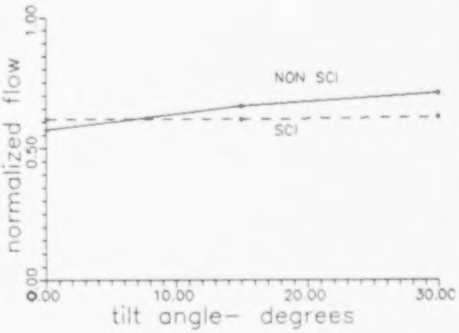

Figure 2. Blood Flow vs. Tilt

COMPARATIVE EFFECTS OF SEATED POSTURAL CHANGE ON SEAT SURFACE SHEAR

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INTRODUCTION

Many researchers and clinicians have indicated a concern about the effects of shear stress acting at the body support interface. Guttman emphasized the importance of distinguishing between purely vertical pressure and shear stress. "Shear stress is much more disastrous for it cuts off larger areas from their vascular supply" (Guttman, 1976). Reichel expressed an opinion that raising the head of a hospital bed by even a few inches was capable of producing sufficient shear force over the sacral area to deprive large areas of tissue of blood supply (Reichel, 1958). Bennett makes the following concluding statements. "Only the existence of large pressure values permits the stable development of large shear values. It is the combination of pressure plus shear that is particularly effective in promoting occlusion. The value of pressure necessary to produce occlusion can be nearly halved when accompanied by sufficient shear. Pressure remains the primary force, not only because of the greater hindrance given blood supply by a unit of pressure as compared to a unit of shear, but also owing to the necessity of the pre-existence of sufficient pressure to permit the stable development of shear" (Bennett et al, 1979).

Other investigators have reported that shear stresses and related tissue deformation is a major aetiological factor in ulcer formation (Dinsdale, 1974; Neumark, 1981; Patterson, 1984). Chow and Odell make the point that shear stress is involved in uniaxial pressure, localized pressure, and any non-uniform pressure distribution or any pressure that causes tissue distortion. This makes shear stress difficult to study because its a result of differential radial expansion between the buttocks and cushions or cushion covers (Chow and Odell 1978).

In addition to shear stresses induced by the normal pressure, there are also shear stresses caused by forces acting tangential to the support surface, i.e. the friction forces. If one differentiates between the types of shear stresses, i.e., pressure or normally induced and tangentially or - induced, it becomes feasible to conceive of methods to measure the simpler tangentially-induced shear forces. That is, if the mechanical properties of the support surfaces remain the same and the body positions are reproducible, determination of the relative tangential shear force acting at the surface will give at least partial insight into this complex interface phenomenon. However, the manner in which the two shear components interact within the tissues will remain unknown.

OBJECTIVE

To investigate the manner in which tangentially-induced (surface) shear forces change with body posture, both within and between Spinal cord injured (SCI) and a non-injured control group

METHODS AND MATERIALS

Two sample groups of subjects were randomly selected; a sample of 10 normal and 12 individuals with spinal cord injury, seven paraplegics and five quadriplegics. A specially designed body positioning chair (BPC) using the same seat cushion was used to obtain consistency between subjects, postures and trials. The seat cushion used was constructed of three layers of 25 mm (1") Sunmate(b) foam (type, soft blue, 5 lb/ft^3). The forces acting tangential to the seat surface were measured in both the fore and aft directions. The BPC seat surface (foam plus plywood substrate) was mounted on an aluminum substructure that moved freely in the sagittal plane. The free movement was limited by load cells mounted at each end of the substructure . The cells measured the forces parallel to the seat surface that tended to move the seat in the fore and aft directions relative to the wheelchair frame. These forces are defined as the tangentially-induced shear (TIS) or friction forces acting at the seat-body interface. The TIS was measured in nine different sitting postures typical of those assumed by SCI individuals while using a wheelchair. The nine study postures are defined below. Mean values and standard deviations for both groups were computed and statistically analyzed. Signifigance was declared at the p= 0.05 level.

Definitions of standard postures

P1M - Neutral Upright Posture: Defined as the posture in the BPC with the pelvis placed as far posteriorly on the seat as possible, trunk and pelvis on the mid-line, and head in contact with the headrest. The seat surface is horizontal with the backrest reclined 10° to the vertical (100°). Arms are comfortably placed on the thighs and footrests are adjusted to take approximately 10% of the body weight.

P1L - Trunk Bending - Left: Defined as the posture in the BPC the same as P1M above, except that the trunk is flexed to the left until the left side contacts the elevated armrests (approximately 15° of lateral trunk flexion.

P1R - Trunk Bending - Right: Defined as the posture in the BPC the same as P1M, except the trunk is flexed to the right side.

P2 - Forward Trunk Flexion 30°: Defined as the posture in the BPC the same as P1M, except the head and trunk are flexed forward 30° along the A/P mid-line

P3 - Forward Trunk Flexion 50°: Defined as the posture in the BPC the same as P1M, except the head and trunk are flexed forward 50° along the A/P mid-line.

P4 - Back Recline 110°: Defined as the posture in the BPC the same as P1M, except the backrest is reclined to the 110° position.

P5 - Back Recline 120°: Defined as the posture in the BPC the same as P1M, except the backrest is reclined to the 120° position .

P6 - Body Recline 10°: Defined as the posture in the BPC the same as P1M, except the whole seat assembly (seat and back) is tilted 10° in space.

P7 - Body Recline 20°: Defined as the posture in the BPC the same as P1M, except the whole seat assembly (seat and back) is tilted 20° in space.

Description of shear measurement instrumentation

The load cells used were Sensortronics(c), model 60040, which are a low profile bi-directional version that is produced in a variety of load capacities. The data acquisition system used was a Metrabyte(d) DAS-16 multi-functional high speed analogue-digital (A/D) I/O expansion board for the IBM PC computer. The front end signal amplification and conditioning was done using a commercial unit from Action Instruments(e), Model AP4051. The Basic software program combined with

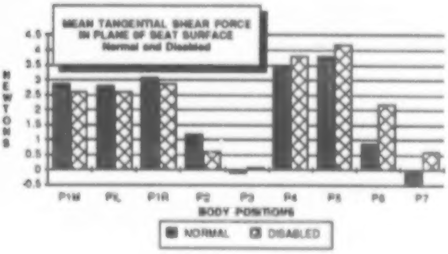

Figure 1. Plot of TIS forces in nine study postures.

the Metrabyte A/D board permitted calibration and adjustment of the baseline settings for the load cells prior to each run. Calibration of the load cells was done using a spring scale. A plot of the force versus voltage output indicated a linearity of approximately 2% within the operating range of the scale (0 - 25 lbs., 0 - 11.3kg). Tests were done to determine the the friction force in the linear bearings, which in turn was used to adjust the recorded values of the loads cells. Regression computations were necessary because the friction values varied slightly with body weight .

RESULTS

Tangential shear force (TIS) acts at the body-seat surface in all nine postures studied (fig 1). With respect to the neutral posture (P1M), maximum reductions of TIS force occur upon forward trunk flexion of 50° (P3) (-133% or a reversal of 33%) and upon full body tilt to 20° (-85%) (fig 2). Extrapolation of these results suggest that full body tilt to approximately 25° reduces the TIS force to near zero. Further tilting causes a reversal and a gradual increase in TIS force in the opposite direction. However, the manner in which the TIS interacts with the normally induced shear stresses to produce potentially deleterious effects within the supporting tissues has not been clarified by this work.

DISCUSSION AND IMPLICATIONS

The TIS has been defined as the force acting parallel to the seat surface that is required to maintain A/P equilibrium. It can be thought of as the friction or shear force acting at the seat surface that prevents the pelvis from sliding forward. It varies with body posture and is largely dependent on the horizontal reaction force applied to the body by the backrest. Horizontal reaction forces at the footrest can also affect the tangential shear values.

Most conventional wheelchairs provide increased trunk stability, especially for tetraplegic patients, by reclining the backrest. Many powered wheelchairs also have a reclining backrest as a powered option. Elaborate designs have been marketed that prevent relative movement between the person and the backrest when reclining takes place. **Based on the results of this study, reclining the backrest creates the highest increases in tangential shear forces at the seat surface.** In addition, the results of this study indicate that backrest reclining drastically increases the tendency for a person to slide forward on the seat surface. To the extent that this sliding is resisted by the seat surface friction (TIS force), potentially damaging tangentially-induced shear stresses can be experienced by the supporting tissues. Also, backrest recline up to 120° has relatively little effect on reducing maximum interface pressure. **A better approach to providing trunk and pelvic stability, reduction of TIS force and reduction in maximum pressure is to tilt the whole body in space.** On average, a tilt angle of 25-30° will reduce the TIS value to near zero, while reducing maximum pressure values by 10-15% from those values experienced in the neutral upright posture (horizontal seat with 100° of backrest recline). In summary, if one desires to maintain low A/P seat surface shear values than body postioning devices that allow full body tilt in space should be chosen in contrast to those that are limited to simple backrest recline.

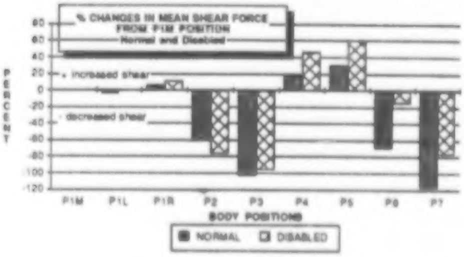

Figure 2. Plot of % changes in TIS values from values in the neutral posture (P1M) as a result of postural changes (P1L to P7).

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11.5

A LOW-COST DATA ACQUISITION SYSTEM FOR MEASURING SHEAR FORCE AND CENTER OF GRAVITY OF WHEELCHAIR OCCUPANTS

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ABSTRACT

A low-cost data acquisition system based on an IBM PC-XT microcomputer has been developed for measuring the tangentially-induced shear force acting where an individual's body rests on the seat of a wheelchair as well as the center of gravity of the wheelchair occupant. The system was principally constructed using a variety of off-the-shelf components.

BACKGROUND

A data acquisition system was required that was capable of simultaneously measuring the tangentially-induced shear stress where a wheelchair occupant rests on the seat of the wheelchair and the center of gravity of an individual seated in a wheelchair. The tangentially-induced shear force measurements were needed to determine the manner in which the tangentially-induced shear force changes with body posture (see Hobson, 1989b elsewhere in this volume). The center of gravity measurements were required to determine the effect of posture on the center of gravity. These measurements were taken as part of a larger study by Hobson (1989a), the purpose of which was to investigate the possible contributions of pelvic and spinal deformity and body posture to spinal/pelvic alignment, pressures across the buttock support area, tangential shear at the support surface, and locations of center of gravity.

METHODS

Two types of sensors were used to acquire the data. The tangentially-induced shear force was measured by two model 6040 Sensortronics load cells. The model selected is a low profile bi-directional cell with a capacity of 0 to 22.6 kg and an overload capacity of 200%. The transducer itself is a loaded beam design with attached strain gages in a Wheatstone Bridge configuration. Front-end signal amplification and conditioning for the load cells measuring shear force was performed by the model AP4051 instrumentation amplifier from Action Instruments. Calibration of the load cells was performed using a spring scale.

The center of gravity of the wheelchair occupant was calculated from the occupant's weight measured by four load cells constructed from cantilevered beams using a design obtained from the Center of Rehabilitation Technology at Helen Hayes Hospital. Each cell was composed of four strain gages, one mounted on each side of each cantilevered cell beam. The capacity for each cell was 0 to 68 kg. Signal amplification and conditioning was performed using a circuit board designed and built at Helen Hayes Hospital and modified for increased noise reduction and for zero and span control by the authors.

The same wheelchair and cushion were used to position each person involved in the study. The wheelchair's seat surface was mounted on an aluminum substructure that moves freely in the sagittal plane. The free movement of the surface was limited by the two cells measuring shear force, one mounted fore and one mounted aft. The cells therefore measured the forces parallel to the seat surface which tended to move the seat in the fore and aft directions relative to the wheelchair frame. The four cells used for determining the center of gravity were mounted in a platform consisting of two parallel rails. The width between the rails and the load cell locations within each rail were variable, so that for future use the each of the cells could be positioned under the wheels of any wheelchair. A ramp on one end of the rails permitted the wheelchair and occupant to be rolled onto the platform.

The data acquisition system was built around an IBM PC-XT microcomputer. The data acquisition was performed by a Metrabyte DAS-16 A/D board. The Metrabyte DAS-16 is a multifunction high speed analog/digital I/O expansion board using a 12 bit successive approximation converter with a 12 µs conversion time. The channel input configuration is switch selectable on the board, providing a choice between 16 single ended channels or 8 differential channels with ±10V common mode range. Throughput (conversions/second) depends on the output configuration. The board was configured to use 16 singled-ended A/D channels. Six were actually used during tests: 1 for each load cell (total of 4), and 1 for each shear cell (total of 2). The selected input voltage range was 0 to 5 volts. A machine language driver for performing the analog to digital conversion for each input channel provided by Metrabyte was called from a compiled BASIC program developed using Microsoft QuickBASIC 3.0.

Readings for measuring the shear stress and weights of the wheelchair occupant on each of the load cells mounted in the center of gravity platform were taken on demand by the The A/D conversion rate for this study was approximately 615 samples per second. The conversion rate varied slightly because of the nature of the conversion process. At the UTREP facility, an unusually high amount of noise proved to be extremely difficult to filter. Because real-time sampling was not a requirement for data collection, 200 sets of samples were taken at once and averaged to give readings for each cell to minimize the effect of noise on the signals from each of the cells. A sequence of calibration tests confirmed that this technique adequately minimized the effects of noise on the input signal. The machine language only cycled through the six channels once per machine language call. The BASIC program, therefore, had to spend time outside of the machine language routine storing the samples in an array variable for further processing. The conversion time for 200 sets of data, including the machine language calls and the processing in BASIC, ranged from 1.93 seconds to 1.97 seconds, or a throughput of 622 to 609 samples per second, respectively.

The system offered two options for data display: tabular and graphic. The tabular display showed the values for both shear stress (displayed in pounds and kilograms) and center of gravity (displayed in inches) as well as the weights on each of the individual cells. The graphic display showed the real-time location of the center of gravity, along with the values of the x and y coordinates.

RESULTS

For each pass of the A/D process, the data acquisition system stored the values for tangentially-induced shear force, the weights recorded by each of the cells under the wheelchair wheels, and the calculated center of gravity. These values were transferred to a spreadsheet program for further analysis.

DISCUSSION

The system was relatively easy to assemble, with off-the-shelf components used for almost every part of the system. The exceptions were the load cells used for the center of gravity measurements, built on-site from a design obtained from the Center of Rehabilitation Technology, Helen Hayes Hospital in West Haverstraw, New York, and the signal amplification and conditioning unit for those cells. The estimated costs for building each of the center of gravity load cells was $250, while the estimated cost of the signal amplification and conditioning unit was $200. Though the Metrabyte DAS-16 A/D board retails for $955, the less expensive DAS-8, listing for $400, would have served equally well for this application. Each shear force cell was purchased for $300. The signal conditioning unit cost $500. Because an IBM PC-XT compatible computer can be purchased for roughly $1500, the estimated cost for constructing a similar system, not including the wheelchair used for positioning, would be approximately $4200.

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COMPARATIVE EFFECTS OF POSTURE ON PRESSURE DISTRIBUTION AT THE BODY-SEAT INTERFACE

11.6

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INTRODUCTION

Studies conducted over the past decade have confirmed that the incidence and related costs of pressure sore treatment remain a major health problem. Both clinical and research evidence, although inconcise and inconclusive, are biased towards excessive and/or prolonged application of pressure as being the primary causative factor. More recently, additional contributing factors have been implicated. Some of these factors are: shear stress, impact loading of tissue, elevated temperature and humidity, age, nutritional status, general health, activity level, deformity, posture and postural change, body stature, and psychological deficits.

It is evident that much remains to be accomplished in the area of pressure and postural management from both the research and clinical perspectives. A few investigators have questioned the primacy of pressure as the leading causal factor in pressure sore formation. The fact remains that there is a dearth of research evidence suggesting any other factor as being more dominant than interface pressure. However, it is also clear that many unanswered questions have persisted and it is now time to more closely examine some of the remaining implicated factors. For example, the role of shear stress, deformity, activity level and alterations of body posture are factors that require improved understanding. In particular, an understanding as to how these variables may interact with interface pressure to yield predictable physiological responses in the supporting tissues. This study attempts to delineate the relationship between changes in seated posture and pressure distribution at the body-seat interface, and how the relationship may differ between spinal cord injured (SCI) and noninjured people.

OBJECTIVE

To identify pressure distribution differences that may exist within and between the able-bodied and spinal cord injured (SCI) population and how the distributions may be affected as a result of deformity and/or alterations in sitting postures.

METHOD AND MATERIALS

Ten noninjured and twelve SCI subjects particpated in the study. Nine typical wheelchair sitting postures, as defined below, were studied. Two Oxford Pressure Monitors (OPM) (Bader,1982; Bader and Hawken,1986) were used to measure the pressure values under the buttock area. Four, 3 x 4 cell matrix transducers (48 cells), were fixed to the seat surface so that their positions relative to a reference axis would remain constant. The transducer array was placed so that the ischial tuberosities of all subjects would fall on the back two arrays (24 cells). The front two transducer arrays were used only to assure that the maximum pressure values actually occurred within the back two arrays. A specially designed body positioning chair (BPC) using the same seat cushion was used to obtain consistency between subjects, postures and trials. The seat cushion used was constructed of three layers of 25 mm (1") Sunmate(b) foam (type, soft blue, 5 lb/ft^3).

The subjects were asked to assume in the P1M (neutral) position on the BPC and pressure recordings taken in the P1M and all remaining 8 standard positions (P1L to P7). Subjects were given a fifteen minute free movement period prior to each recording series in order to allow the seat foam and measurement equipment to reach steady state. Maximum pressure values, location of maximum values, mean average pressure values and mean peak pressure gradients were all computed from the recorded data. The subjects were not removed from the BPC between changes in body postures, thereby minimizing errors that could result from inaccuracies associated with reseating subjects (Bader, 1982). Successive pressure recordings were taken in one posture in order to conduct repeatability and variability checks on the pressure measurements. Calibration of the equipment was done as per the developer's recommendations at the beginning of each trial, and again at the end of those trials in which any comparatively high or low values were observed.

Definitions of Postures Studied

P1M - Position: Defined as the posture in the BPC with the pelvis placed as far posteriorly on the seat as possible, trunk and pelvis on the mid-line, and head in contact with the headrest. The seat surface is horizontal with the backrest reclined 10° to the vertical (100°). Arms are comfortably placed on the thighs and footrests are adjusted to take approximately 10% of the body weight.

P1L - Trunk Bending - Left: Defined as the posture in the BPC the same as P1M above, except that the trunk is flexed to the left until the left side contacts the elevated armrests (approximately 15° of lateral trunk flexion.

P1R- Trunk Bending - Right: Defined as the posture in the BPC the same as P1M, except the trunk is flexed to the right side.

P2 - Forward Trunk Flexion 30°: Defined as the posture in the BPC the same as P1M, except the head and trunk are flexed forward 30° along the A/P mid-line

P3 - Forward Trunk Flexion 50°: Defined as the posture in the BPC the same as P1M, except the head and trunk are flexed forward 50° along the A/P mid-line.

P4 - Back Recline 110°: Defined as the posture in the BPC the same as P1M, except the backrest is reclined to the 110° position.

P5 - Back Recline 120°: Defined as the posture in the BPC the same as P1M, except the backrest is reclined to the 120° position .

P6 - Body Recline 10°: Defined as the posture in the BPC the same as P1M, except the whole seat assembly (seat and back) is tilted 10° in space.

P7 - Body Recline 20°: Defined as the posture in the BPC the same as P1M, except the whole seat assembly (seat and back) is tilted 20° in space.

RESULTS

1) Average pressure distribution between populations is effected insignificantly by alterations of sitting posture. Forward flexion of the trunk causes the largest decrease within both groups from the average pressures in the neutral position. On average, a reduction of approximately 15% from the values in the neutral position occurs at 50° of trunk flexion (P3).

2) Mean maximum pressures of individuals with a SCI are significantly higher than able-bodied individuals in all nine sitting postures studied. In the neutral posture, on average, the maximum pressure for a person with a SCI is 26% higher.

The differences range from a low of 6% in the P5 position to a high of 46% in the P2 position.

3) The maximum pressures can be reduced by postural changes from those values occurring in the neutral P1M posture. These reductions are; lateral trunk bending 15° (32-38%), forward flexion to 50° (-9%), backrest recline to 120° (-12%), and full body tilt to 20° (-11%).

4) Alterations to sitting postures causes similar changes to the A/P location of the maximum pressure (Pmx) for both disabled and able-bodied. With respect to the neutral posture, forward trunk flexion of 30° and 50° results, on the average, in a posterior shift of 2.4 and 2.7 cm, respectively. The largest posterior shift of 6 cm occurs in the backrest recline 120° (P5) posture.

5) On average, individuals with spinal cord injury have peak pressure gradients that are 1.5 to 2.5 larger than non-injured people. Among the postures studied maximum reduction of the peak gradients from those measured in the neutral posture occur after backrest recline to 120° (P5) (-8%).

DISCUSSION AND IMPLICATIONS

The average pressure distribution across the critical buttock area varies little between normals and individuals with paralytic injuries. Furthermore, typical alterations in postures assumed while sitting in a wheelchair have minimal effect on the average pressure distribution. Forward flexion of the trunk to 30° is required to obtain a reduction of about 15% from the average pressure values in the neutral posture.

People with a spinal cord injury have maximum pressures that are significantly higher than able-bodied individuals in most postures typically assumed in a wheelchair. The differences in mean maximum pressure range from a minimum of 6% in the backrest recline 120° posture to a maximum of 45% in the forward flexed posture 30° (P2). The difference in the neutral posture (P1M) is about 25%. It is concluded that these inherent differences in mean maximum pressures are largely due to asymmetrical ischial loading caused by spinal/pelvic deformities and atrophy of tissue over the ischiae.

Changes in posture can effectively reduce the maximum pressures of SCI people from those values that are present in their neutral sitting posture. On average, recline of the backrest to 120° reduces the neutral values by 12% as does the full body tilt to 20° (11%). Forward trunk flexion to 50° yields a reduction of 9%. Lateral bending to 15° reduces the neutral values by 30-40%.

The implications of these findings are possibly more important from a research perspective. They suggest that caution must be exercised when using normal subjects and absolute pressure values to make judgements about the pressure distribution characteristics of commercial cushions or generic seating materials. Also, shape and pressure contour derived from normal subjects can yield profiles that are misleading regarding the characteristics of paralytic buttock contours.

A peak pressure gradient has been defined as the maximum gradient between any two adjacent pressure recording cells. According to the definition of the peak gradients used in the study, the peak gradients are directly related to the maximum pressure. Therefore, the peak gradients are also inherently higher for the paralytic group in all sitting postures. On average, peak gradients are higher by 1.5 to 2.5 times depending on the assumed posture. These values can be reduced through reduction of maximum pressures through alterations of posture.

The implications from these findings are several. First, shear stress theory implies that the higher the force gradient between two points the higher the induced shear stress. The body-support interface is a complex arrangement of bony prominences, overlying tissue, clothes, transducer, cushion cover, and supporting materials which are all subjected to both normal and shear loading. Therefore, it is very difficult to make accurate determinations as to the exact nature of the shear stresses in the tissues. However, it seems reasonable to assume that if high pressure gradients are recorded by the transducer matrix, these gradients should, in some manner, be related to elevated shear stresses in the supporting tissues. Secondly, if shear stress acting in combination with high normal loads presents a critical combination of events as proposed by Bennett et al (1979) and Chow and Odell, (1978) then knowledge of cushion materials and postures which minimizes these occurrences is vitally important. It follows that a simple measurement of maximum pressure in one static posture may not yield the information necessary to minimize the critical combination of normal pressure and shear interacting at a pelvic location under high risk of ulceration.

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TELECOMMUNICATIONS FOR THE HEARING IMPAIRED: FROM BAUDOT TO ASCII

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INTRODUCTION

When Alexander Graham Bell invented the telephone, he certainly could not have foreseen the problems he was creating for hearing impaired people. The telephone has become an accepted part of everyday communication in this country, but it remains a major barrier for those who cannot hear. The barriers presented by the telephone are particularly severe for those hearing impaired people who are deaf, but there are still many ways in which advanced technology could be applied. Before this technology can be applied, a basic change which must be made in the devices deaf people use to communicate by telephone. The system must switch from Baudot code to ASCII.

For most deaf and severely hard of hearing people, telecommunications involves a TDD, a Telecommunications Device for the Deaf. The TDD system which exists in the United States is marvel, a tribute to the ingenuity and persistence of many people dedicated to opening the doors of telecommunications to the deaf. Unfortunately, it has been sidetracked into a technological dead end through its dependence on Baudot code.

In Baudot code, each character is made up of 5 binary bits. This means that the total number of unique characters available is limited to 32 (2 to the 5th power), the 26 characters of the alphabet and 6 other characters. There is no distinct code for upper and lower case characters, no code for the many special symbols which have come into use. The Baudot code is clearly unable to meet the needs of modern electronic communication.

Since 1968 ASCII (American Standard Code for Information Interchange) has been the standard in the United States. ASCII uses an 8-bit character, but the eighth bit is usually not used. The first 7 bits allow for 128 unique characters. There have been several 8-bit variations with 256 characters, the most common one being the "Extended ASCII" code that IBM released when they introduced their line of personal computers in 1981.

The TDD system got its start in surplus telephone equipment. About 1960, Dr. James Marsters of Pasadena, California, obtained a surplus Teletype Model 32ASR and gave it to a deaf scientist, Robert Weitbrecht, with the request that he develop some way for them to use it to communicate by telephone. Weitbrecht took an acoustic coupler, modified it to work with the Baudot system, and used it to connect the Teletype machine to an ordinary telephone handset. The resulting system was first demonstrated at a meeting of the Alexander Graham Bell Association for the Deaf in 1964.

Testing and development continued, but growth was limited by the availability of Teletype machines. By 1968 only about 25 machines were in operation. In that year AT&T decided to donate surplus Teletype machines to deaf people. Over a period of years, several thousand Teletypes were distributed.

Eventually, the supply of old Teletypes was depleted. A new source of equipment was needed and during the 1970's, many small companies were established to manufacture and market TDDs. Interse competition for a limited market drove the majority of these companies out of business.

As the market matured, the TDD evolved. The TDD of today is a sleek book-sized plastic box consisting of a phone cradle, LED strip, and a keyboard. It looks far different from the old Teletype machines, but it still functions in essentially the same way as Weitbrecht's original Model 32 Teletype and acoustic coupler. Therein lies the problem: The current TDD system is good, but not good enough.

SHORTCOMINGS OF THE BAUDOT TDD SYSTEM

Outdated. The basic problem with the Baudot TDD system is that it is outdated and outside the mainstream of current computer technology which uses the ASCII standard. By adopting an obsolete communications standard, the deaf population has forced itself to buy customized equipment which fails to take advantage of the features available in modern personal computers.

Incompatible. The second problem is that Baudot and ASCII are two completely incompatible codes. The ASCII code used by most computers in the United States is a 7-bit, 128-character code. The Baudot system used by the deaf is a 5-bit, 32-character code. Conversion from one code to another is not a major problem. The difficulties lie deeper.

Different transmission speed. TDDs and computers both utilize digital signals for communication. A TDD or computer uses a modem to modulate a digital signal into an analog signal and send it over the telephone line to another modem which demodulates the signal into digital form for the other computer or TDD. The term "baud" is used to indicate transmission rate of the signal. It refers to the number of times the carrier signal is modulated per second. TDDs and computers use different baud rates for telephone communication. The Baudot TDD system operates at 45.45 baud, a rate far below that used by computers. The baud rate for computer communication over ordinary telephone lines has steadily increased to as much as 9,600 baud.

Now consider what this means in practical terms. In traditional ASCII communication, one start bit and two stop bits are often added to each 7-bit character, making a 10-bit block. At 300 baud this would be a sending rate of 30 characters per second. At 9600 baud it would be 960 characters per second. Data compression techniques have been developed to the point where sending rate is not necessarily 1/10 the baud rate. The fastest 9600 baud modems can send the equivalent of up to 1,920 characters per second. By comparison, a TDD system which uses one start bit, a five-bit character, and two stop bits and sends at 45.45 baud will send 5.8 characters per second. This is roughly 60 words per minute, a speed most good typists can exceed.

Half-duplex only. Another area of difficulty is the fact that the TDD system used by the deaf is characterized by its half-duplex mode of operation. Half duplex means alternating communication over a single channel. When one person is sending, another person cannot send until the first person stops. Full duplex means communication over two channels simultaneously. Two people can send and receive at the same time. Most computer communication is full duplex. TDD communication is half duplex. Most deaf people who use a TDD have had the experience of being unable to interrupt while the person on the other end of the phone types merrily on about some subject that is already known.

STRENGTHS OF THE BAUDOT TDD SYSTEM

Large existing equipment base. No one really knows how many Baudot TDDs are in use in this country. Manufacturers do not release their sales figures, and even if they did it is very difficult to determine how many old TDDs are still working. Some of the old TeleType Model 15's are still functioning after more than 50 years of service. An educated guess by the author is that 150,000 or 200,000 TDDs are currently in use. The TDD system keeps expanding, especially as more and more states are offering free TDDs to hearing impaired people. States that have offered free TDDs are unlikely to purchase a completely new generation which is incompatible with existing TDDs.

Especially suited for its special purpose. The modern Baudot TDD is a specialized piece of equipment designed for straightforward person-to-person communication over telephone lines. In spite of its shortcomings, the system has several features which make users reluctant to give it up.

1. It is simple to operate. A person puts the telephone handset on the TDD cradle, dials the desired number, waits for a response, and begins typing when a response is received. There are no programs, no menus, nothing complicated to learn.

2. It is reliable. Since TDDs tend to be relatively simple, most of them can take an amazing amount of abuse and still keep functioning. The signal itself is robust and is seldom seriously affected by poor connections or "dirty" phone lines.

3. It is tolerant. TDDs, unlike most computer communications equipment, are not designed for data security. This means that they will tolerate having the connection broken and then reestablished, as happens when someone picks up the handset to listen and then puts it back down on the coupler.

Note that each of these features are something designed into the TDD equipment, they are not inherent characteristics of the Baudot or ASCII codes. It is quite possible to have an ASCII system that is simple, reliable, and tolerant.

ADVANTAGES OF AN ASCII TDD SYSTEM

Allows use of standard computer parts. Switching to ASCII code would put the TDD system squarely into the mainstream of computer communications. TDD equipment could utilize standard computer parts and the cost of these parts becomes lower every year.

Permits TDDs be much more powerful. ASCII TDDs would be able to incorporate many sophisticated computer functions without major increases in cost. Automatic dialing, automatic answering, built-in message services, and many other features could all be made standard.

Encourages integration into the general telephone system. The telephone system in the United States is rapidly becoming completely computerized. Switching to ASCII would put the TDD system on the path of being integrated into that system. It might be possible for a TDD to be automatically recognized by the central telephone system and to communicate directly with it. This could lead to a multitude of services, ranging from directory assistance to electronic mail and automatic relay systems.

Greatly broadens the communication base. There are more than 20 million personal computers in use in the United States and millions more are sold each year. With the addition of a modem and appropriate software, each of these computers has the potential of communicating with an ASCII TDD system. This would provide a tremendous communication base and would expand the TDD system far beyond its current state.

BRIDGING THE GAP

The bottom line is that the current Baudot TDD system has many good features but is woefully outdated and technologically limited. To update the system and put it into the mainstream of technology it is necessary to switch to ASCII. The problem is to bridge the gap between Baudot and ASCII without losing the good features of the current Baudot system. This is not a simple problem and there is no simple solution.

The most workable approach is to incorporate ASCII into the existing system and slowly phase out Baudot. This means making TDDs that can use both Baudot and ASCII until everyone has ASCII capability and Baudot is no longer used. This would need to be done over a period of years. Several things could be done to encourage this.

Industry agreement. There are only five manufacturers of TDD equipment in the United States. All are members of Telecommunications for the Deaf, Inc. (TDI), a consumer-oriented membership organization that provides leadership in the area of deaf telecommunications. TDI could encourage manufacturers to make all TDDs ASCII-compatible. At the moment only some TDDs are ASCII-compatible and this feature is usually sold as an extra-cost feature.

Government purchase. Federal, state, and local governments could bring about the change in just a few years by requiring that all equipment intended for use as a TDD and bought with government funds have ASCII capability. This does not necessarily require legislation. It could be implemented simply as an administrative policy.

Education of deaf consumers. The deaf population has come to think of the Baudot TDD system as simple and familiar. The switch to ASCII represents a switch to a new and unfamiliar system. The change can be made considerably easier if deaf people are provided with basic information about ASCII and are convinced that converting to ASCII is worth the effort it requires.

Education of hearing consumers. The general population must be taught the fundamentals of communicating by telephone with deaf people. With all the millions of personal computers in use, there is no reason why this equipment cannot be made a part of the general communication base available to deaf consumers. If correctly set up, this communication could be much more satisfactory than indirect communication through interpreters and relay services.

Standardization of telephone status indicators. A general problem which faces the developers of telephone communication equipment for deaf people is the lack of standardized signals for indicating line status. If developers could depend on each different telephone line status signal having its own standard audio tone, the task of developing low-cost electronic equipment to detect and identify these signals would be much easier.

ASCII-Baudot-voice differentiation. A hearing person can easily tell whether the sound coming over a telephone line is from a computer, a Baudot TDD, or a person. A deaf person is unable to make this distinction, a fact which often leads to a great deal of confusion and wasted time. It would be very helpful if there were a small, inexpensive "black box" which could be attached to a telephone line to indicate not only what communication mode was being used, but also indicate the baud rate of an ASCII signal and discriminate the many line status signals. Another desirable feature of this "black box" would be multiple telephone line outlets and either automatic and manual switching to the line with the appropriate equipment attached.

Simpler computer communication software. A computer program especially designed to allow two technically unsophisticated people to communicate using home computers with inexpensive ASCII modems would go a long way toward encouraging deaf people to use home computer equipment in place of their Baudot TDDs. A good shareware program of this type would be quickly passed around the deaf community.

Small, low-cost, hybrid TDD equipment. For their communication needs, deaf people want equipment that is light, portable, and inexpensive. They want something that doesn't take up too much space on a kitchen counter and which is small enough to throw into a suitcase when they travel. They want it to be inexpensive enough so they can have one for each telephone extension in their home; and so that their family, friends, and others can be more easily encouraged to buy one. As personal computer equipment becomes smaller and less expensive, its use by TDD manufacturers to create hybrid TDDs will give an added incentive toward an all-ASCII system.

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A SCANNING PROGRAMMABLE REMOTE CONTROL

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ABSTRACT

For the disabled who can operate only one or two ability switches, an interface is necessary for them to take advantage of the recent introduction of low-cost domestic audio/visual equipment with full-function infrared remote control. A scanning programmable IR remote control was developed to achieve this aim.

BACKGROUND

A centralized environmental control system has been developed for use in high density, multi-level, multi-unit buildings.

The environmental control system is modular in design. It consists of a Master Control, a Relay Box and a number of special purpose interface units. The Master Control and the Audio/Visual Interface is shown in Figure 1.

The Master Control has sixteen scan positions. The function of each position is listed below: -

Position	Function
1-8	appliance on/off control
9	reserved
10	Telephone Interface
11	Audio/Visual Interface
12,13	Intercom
14	Electric door lock
15	Alarm/door lock
16	All off (except alarm)

In the manual scan mode, device and function selections are made with two switches. In the auto-scan mode, with the exception of the intercom function, only one switch is necessary. Two switches are provided on the front panel and an external dual switch can be connected. The device can also be controlled remotely with a two channel ultra-sonic remote control using frequencies compatible with the TASH Ultra-Four.

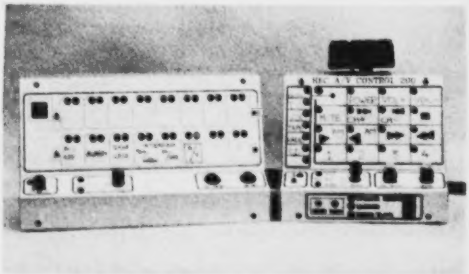

Figure 1: Environmental control with Audio/Visual Interface

Communication between the Master Control and a special purpose interface relies on a simple bus and simple handshake protocol. Once handshake is established, control as well as control signals from the switches or ultrasonic receiver are passed to the selected interface until the (return to) MASTER (Control) function is activated.

METHOD

The Audio/Visual Interface has a scanning console. A one meter cable carries the drive signal from the interface to the infrared emitters housed in a small plastic case with a microphone holder mounted on the base. The A/V Interface can accommodate up to six devices with fifteen programmable functions each. As in the Master Control, two switches are required for operation in the manual scan mode but only one is required in the auto-scan mode.

When control is passed to the A/V Interface, scan of the seven-position Device Selection Column starts. The first position is the Master Control. When one of the A/V devices is selected, scan of the sixteen position Function Selection Matrix begins, starting from the Return to Device Selection. When any other function is activated, the corresponding code will be transmitted.

The following steps are required to program the A/V interface: -

1. Toggle the Normal-Learn switch to the Learn position. The LEARN MODE indicator will light.
2. Select the device and function. The OPERATE REMOTE indicator will light.
3. With the other remote control facing the red plastic window, press the key to be programmed until the LEARNED indicator lights.

A 68705P3 single-chip computer is used as the interface element for a commercially available Yamaha MRX-100 Learning-capable Multi-function Remote Control. This control was chosen because it has a large storage capacity for long codes. The casing and keypad of the MRX-100 are discarded and key depressions are emulated by analog gates under the control of the single-chip computer.

To reduce the cost, an ultrasonic receiver and power supply are not built into the A/V Control. In its current form, it can work as a stand-alone unit with power from an AC adaptor.

DISCUSSION

Although the MRX-100 was chosen for this project, the method of using analog gates to emulate mechanical switches should be applicable to other commercial programmable remote controls.

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DEVELOPMENT OF A LOW-COST COMMUNICATION AND ENVIRONMENTAL CONTROL DEVICE TO INTERFACE WITH COMMERCIAL CONSUMER APPLIANCES

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ABSTRACT

Most commercially available communication/control devices for profoundly disabled people are installed at the bedside and physically linked to the room's wiring and appliances.

Changes require the input of a highly-trained therapist to upgrade or add functions. The MARK II Graham Clarke system has been designed to overcome these limitations. The modular nature of the hardware and software enables the system to grow in size, cost and complexity as the user's needs demand. A further novel feature of the system is that the control link between the user and the 'world' is small, portable and uses a Infra-Red light beam, 2-way wireless. It is hoped that the system will soon become commercially available.

INTRODUCTION

The advent of the microprocessor - often invisibly embedded in home/consumer appliances, has lowered the cost, increased the power and widened the availability of fairly complex modern technologies to the public at large. Systems ranging from home security to VCR's can now be programmed to act automatically or by remote control, without computer knowledge.

Sadly, manufacturers have either ignored or been unaware of just how useful these systems would be, not as labour-saving devices, but as enabling devices for severely disabled people.

The Graham Clarke system which has been under intensive development for three years promises to provide a standardised portal for people with good cognitive function to control their micro-environment and thus enjoy a degree of independence which has hitherto been denied them.

Graham Clarke was a typical "locked-in syndrome" client who asked for our help. After intensive therapy he had plateaued with complete residual paralysis except for some control over neck muscles, poor breath control and no speech. We reported on the MARK I system at RESNA 1987.

However, our experiences have since led to major changes in design philosophy, the primary being the adoption of a "you pay only for what you need approach". Most environmental control/communication systems have redundancy in input and output modalities to support many types of disability and controlled appliance. This adds to cost and complexity. Our approach is radically different.

DESIGN

The basis of our system is a pair of INTEL 8052-BASIC single board microcomputers in suitable enclosures which communicate by a full duplex (2-way) 9.6 Kbaud Infra-Red (I-R) light link. We chose I-R over radio because of its greater noise immunity, data channel capacity and most importantly, the ability to emulate the modulation codes of most stereo/video/hand-held appliance controllers. It can therefore directly control these target devices.

The first microcomputer is called the LAND BASE since it is the fixed executor of commands from the second ROVING BASE micro, which stays with the user, on the bed or wheelchair. Each device is 'aware' of the state of the other, and they keep themselves updated about commands sent/received/acted on, in realtime. This means that the user has only to look at a small console of LED's or optional alphanumeric LCD display to know whether certain expected results have been achieved. An example of this is that should the front door have been remotely unlatched for a visitor, a "transaction complete" confirmation will only be given once the door has opened and been reshut. This "closing of the cognitive loop" is regarded as essential if someone who is confined in a remote site by his disability is to have a feeling of security as well as independence.

Because abilities, both expressive and receptive, vary so much with individuals, our modular plug-in user interface serves to allow the therapist to choose the most appropriate physical switch, input servicing card, and status display for the personal needs of the client. At present, inputs include one switch, two switch, IBM joystick emulator (can work as 4 switches or as a 2-channel Analogue-to-Digital input). Built in are two standard "outputs", a speaker and LED status display.

There are two RS232C ports on the roving base. These would typically be used for down-line loading appropriate software to control appliances (as selected) or to create a programme development environment while in communication with a personal computer. (This could be called "Learning Mode"). In "Usage Mode", typically one port would be occupied by a LCD display (or speech synthesiser; we use BIGMOUTH), while the other would service the I-R Transmit - Receive Module (which can also operate in stand-alone mode as a RS232C Communications Link with its paired destination unit). Other features of the Roving Unit are low-battery audio/visual warning, 10-35 V DC switched-mode power supply, and all-CMOS low-power consumption circuitry.

Since high-level-lesion powered wheelchair users often are skilled at head or chin-joystick control, we use the same joystick for controlling devices, merely by changing the mode of the roving base from "wheelchair" to, for example, "cursor control" of a lap-top or desk-top PC. (This can also be used for computer games.) Another local (on-chair) mode is an emergency-call using the built-in speaker. A spare socket is provided to plug in appropriate software in ROM as an alternative to loading it down-line to RAM (avoiding the possibility of loss or corruption).

By contrast, the fixed LAND BASE unit is mains-powered and is essentially a command-handling device and return-message communication server for the user. It uses an identical 8052 BASIC motherboard but has more "executive" outputs: Up to 10 AC mains switches for turning appliances on or off. These can have dimming functions eg for lights. Two RS232C serial ports are available for a desk-top PC or other digital devices (some VCR's now have digital control inputs). Naturally, one serial port is occupied by the other half of the INFRA-RED 2-way-pair providing the wireless soft link with the ROVING BASE. There are other digitial I-O lines for command and status information to/from devices such as autodiallers and X-10 household controllers.

Since others also need to control devices, all AC appliance control outputs can be overridden from a bank of switches on the LAND BASE.

Like the Roving Base, the LAND BASE can be programmed manually in BASIC from an external PC, can be down-line loaded from an external disk library or have a 8K program ROM inserted in an easily accessible socket.

It should be noted that no computer knowledge is needed to load the chosen software "appliance drivers". It is envisaged that the therapist, having done a full assessment of the capabilities and needs of the disabled client, will simply insert the appropriate modules and load their servicing software from a menu, using a simple mouse-pointer selection system on a PC.

THE FUTURE

Recent developments in the consumer market, particularly the "smart house" concept, and intelligent RS232 driven devices such as the "All for One" Universal Infra-Red appliance controller, lend themselves to interfacing with disabled users. In fact, at present the U.S. Electronic Industries Association is drawing up protocols in Single-Room and Whole House environments to ensure that some uniformity can be ensured. The needs of disabled people as consumers must be accommodated in these decisions, with particular reference to remote control of the home environment.

CONCLUSION

The culmination of three years of work has resulted in a unique combination of modularised hardware/software and Infra-Red wireless communication, which could revolutionise the way in which disabled people live. The possibility of remote communication/ control with home microcomputers, appliances, and people at distant points will give new independence and self-confidence even to the severely disabled and the freeing up of family and helpers from many chores which are demeaning to all concerned.

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A DESIGN AND IMPLEMENTATION OF INTEGRATED REAL-TIME EYE MOVEMENT MONITORING SYSTEM

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ABSTRACT

This paper describes design and implementation of the real-time digital data acquisition and monitoring system for eye movements. This system is applicable to various experiments involving physiological, clinical as well as rehabilitation researches. An eye-mark recorder is used as the input device to measure the x-y coordinates of eye movements together with the front view. The numerical and image data are stored on real-time basis into a personal computer. The main object of the system design is to integrate friendly user interface and database in order to fully utilize eye-mark recorders.

INTRODUCTION

The monitoring of eye movements plays an important role in analyses of human cognition of visual information. For this purpose, eye-mark recorders with video cameras have been developed. Their field use, however, has a disadvantage of requiring tedious and repetitive mirror adjustments. This discourages many potential users to introduce the recorders, although they have many advantages over other methods.
The system reported in this paper eliminates the necessity of the adjustments by means of connecting a personal computer to an eye-mark recorder and ,at the same time, constructs database of numerical and image data in digital fashion.

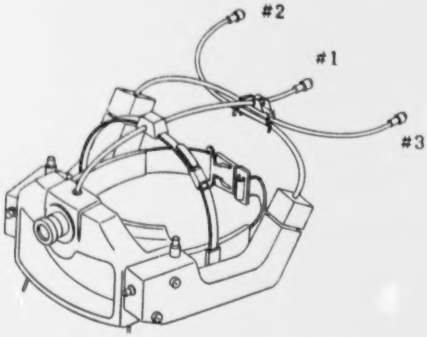

Fig.1. Eye-mark Recorder.

SYSTEM CONFIGURATION

Fig.1 shows the eye-mark recorder made by NAC Co. The cable #1 is connected to a camera mounted on the top of the head harness. This camera takes the image of front view containing LED reference points, which are used to correct the x-y coordinates of eye movements measured by two cameras (#2 and 3). Fig.2 illustrates the schematic connection of equipments composing this system. The controller is a part of the recorder and arranges the three camera views into one monitor screen. The VCR and TV set are both of conventional home use for recording and monitoring purpose and can be omitted from the system. The dotted arrows indicates the back sides of the J-3100 (Toshiba T-3100 Japanese model) and the optional expansion box containing image digitizer and GPIB interface board. The software of this system is written in Turbo-Pascal and its

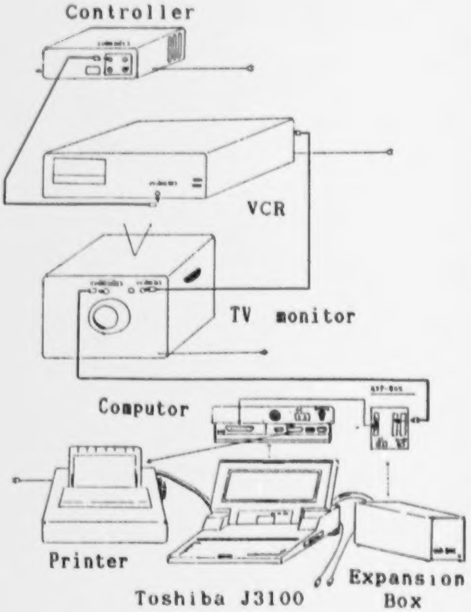

Fig.2. System Configuration.

size is about 3,000 lines. Fig.3 shows the data flow diagram. Each block in the figure stands for the major program modules and interfaces. The data transmission time required to store 250x250 dot screen image with 8 bit brightness data is 1/60 sec. The baud rate of x-y coordinate data is 9,600 BPS.

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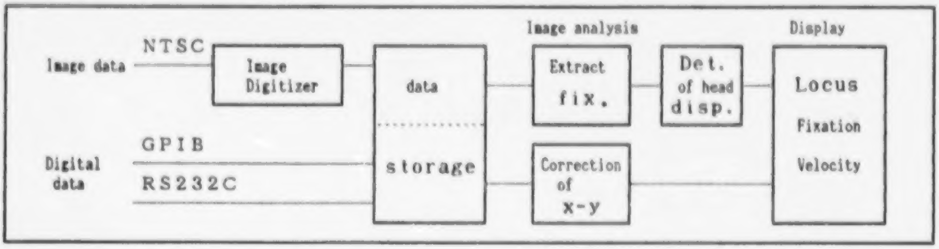


Fig.3. Data Processing.

EXAMPLES

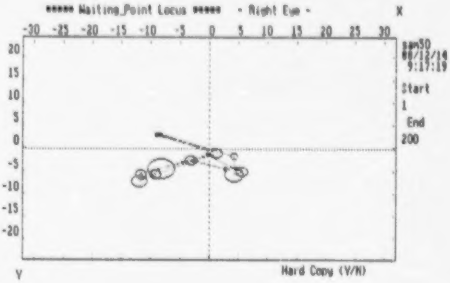
This system is capable of displaying and hard-copying various graphics in addition to regular raw numerical x-y coordinate data. In order to demonstrate the effectiveness of this design approach, the following two types of graphic functions are implemented.

(1)Loci of eye movements.
(2)Frequency and duration of the fixation pauses.

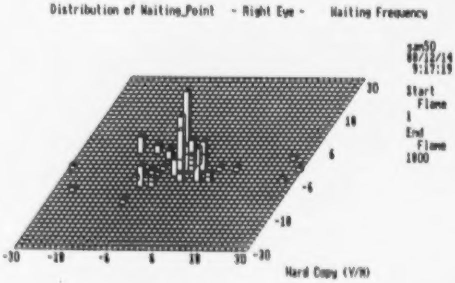
Note that any functions can be added by means of appropriate program modules.
Fig.4 shows one of graphic outputs for the fixation pauses obtained from an experiment, in which a subject was shown 4 pictures projected each on the quadrant of a screen. The subject is asked to look at the screen center and then instructed to search for a particular picture. The eye movements thus start from the center to the objective picture are measured.
In (a), shown is the locus of eye movement. The small circles are proportional to the duration of fixation pauses. (b) is a different graphical interpretation of (b). From these figures, distribution of fixation pauses around the particular picture can be observed very clearly.

CONCLUSION

This system makes even unaccustomed users to fully utilize eye-mark recorders with very small amount of training. The digital and graphic database can be easily used for later analyses of eye movements.



(a). Locus and Fixation.



(b). Fixation : Frequency.

Fig.4. Fixation Pauses.

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DR. GAIT: AN EXPERT SYSTEM FOR GAIT ANALYSIS.

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This abstract describes the design and implementation of two expert systems for gait analysis. These systems analyze the motions of patients with cerebral palsy. The first system, Dr. Gait-1, uses a strict rule-base approach to gait analysis. Because of the complexity involved in gait analysis, the rule base grew to be extremely large. The second system, Dr. Gait-2, reasons using a model of gait in order to form a diagnosis. By modeling the torque-producing forces in gait, Dr. Gait-2 is able to diagnose a wider range of gait pathologies. Both systems were implemented and tested over a variety of gait pathologies.

INTRODUCTION: Gait analysis is a complex task involving the identification of gait pathology from data produced by gait analysis laboratories. Having an objective, computerized system for interpreting gait laboratory data will ensure a standardized, high quality level of analysis, decrease the time involved in doing an analysis, and be a tool for the instruction of gait analysis.

PURPOSE: Using artificial intelligence techniques, the goal of this project is to a) design, build and evaluate an expert system for analyzing the gait of patients with cerebral palsy, b) design a qualitative model of the interacting torque-producing forces in human gait, c) prescribe a therapy based on the interpretation of the gait data, d) have the system learn from experience, and e) provide a model of problem solving for the extension of system capabilities to include patients with other gait pathologies.

METHOD: This project has involved the design and implementation of three generations of knowledge based systems. The first program, Dr. Gait-1, was built to mimic the reasoning of a gait expert as closely as possible in order to identify his knowledge. This system is built using GENIE, a rule based interpreter. The approach used in this system matched patterns of symptoms to causes, and did not deal with gait deviations and causes individually. This system takes as input motion data obtained from the gait study as well as the data normally used by clinicians and physical therapists. The output of the system is a report detailing the problems identified in the case and the reasons why this determination was made.

Dr. Gait-2 involved the redesign of the first system to be a more generic prototype describing the physiologic principles of gait. It still used the GENIE inference engine, but organizes its knowledge differently. Patient data is stored in frames, medical knowledge is represented in a knowledge base, and a set of data preprocessing analysis modules have been added. Dr. Gait-2 fully automates the interpretation of the motion data gathered from the gait study.

Dr. Gait-2 also incorporates an underlying model of gait into the explanations the system produces instead of simply citing a rule from its knowledge base. To do this, Dr. Gait-2 employs a qualitative physical model of the interacting torque-producing forces in human gait and compiled knowledge of how various forces in human gait are affected by changes in body conditions from the norm because of a particular disease. This model allows the effects of individual faults to be determined and also explicity captures the interaction between various faults. The system also prescribes therapies in response to the faults it identifies, and the relative merits of each therapy. One limitation of this system is it is restricted to considering sagittal plane motions.

RESULTS: Dr. Gait-1's performance, particularly in cases involving multiple deviations, is limited because a new rule is required to be included in the rule base each time a new situation is presented. Over 500 rules were generated, making the rule base extremely large and unwieldy.

The Dr. Gait-2 system was successfully designed and implemented. It was evaluated on 40 cases ranging over different types of CP ambulatory patients by comparing it to the report previously written by the expert. For the set of test cases, the system correctly identified 89% of the specific gait deviations (151 of 170). Dr. Gait-2 also identified 46 deviations not mentioned in the case reports. Most of these additional identification deviations are minor. Of the 196 deviations the system identified, it found the correct cause 96% of the time (187 of 196). Dr. Gait-2 recommended the correct therapy 45% of the time, partially correct therapies at a rate of 51%, and incorrect therapies 4% of the time.

CONCLUSIONS: As the evaluation indicates, Dr. Gait-2 is able to correctly diagnose and treat most of the abnormal gait motions it is intended to handle. The program still suffers from several limitations that need to be overcome. First, the program's representation of time is very elementary; the gait cycle is divided into a fixed number of phases and each phase is treated as an atomic unit of time. Second, the system's qualitative model of muscle and body torques is functionally limited because it does not describe the torques within a normal gait cycle; but only tries to explain deviations from normal. Third, the program is limited in its domain; viz. analyzing motions of one leg in the sagittal plane during a single gait study of a patient with CP. The program does not use its experience to enhance itself, and as a result, the system is brittle.

The next generation of gait analysis expert system is currently under development. This system, QUAWDS, includes the knowledge used to construct Dr. Gait-2. It is more robust with respect to the domain and more extensible. This system uses Generic Task theory for structuring the knowledge base. QUAWDS will use data of both legs, all three planes, and the patient's past visits. The project is also investigating a learning strategy for identifying and correcting flaws in the system using the expert's interpretation of a case.

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CARDIOVASCULAR RESPONSES TO FNS-INDUCED ISOMETRIC LEG EXERCISE DURING LOWER BODY NEGATIVE PRESSURE

13.1

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ABSTRACT

Seven able-bodied males underwent progressive lower body negative pressure (LBNP) for the purpose of investigating cardiovascular and metabolic responses to graded orthostatic stress during concurrent functional neuromuscular stimulation (FNS) of thigh and calf muscles. Progressive LBNP at 0, -15, -30 and -45 Torr produced an expected fall of both cardiac output and stroke volume coincident with peripheral venous blood pooling. However, cardiac output was significantly increased by 1.01-2.05 $l \cdot min^{-1}$ ($p \leq .05$) during pulsatile FNS-induced isometric contractions of the lower extremities over 0 to -30 Torr LBNP. The augmented cardiac outputs were produced by increased stroke volumes (6-31 $ml \cdot bt^{-1}$) and elevated heart rates (4-10 $bt \cdot min^{-1}$). Mean arterial blood pressure was also maintained by FNS-induced leg contractions in the face of orthostatic challenge (mean increase = 7.1 Torr), primarily due to increased systolic blood pressure. These data support the view that lower-limb FNS augments central hemodynamic responses in able-bodied men both by enhanced venous return consequent upon activation of the skeletal muscle pump and/or by an increase of sympathetic tone.

INTRODUCTION

Previous research which has investigated the cardiovascular effects of functional neuromuscular stimulation (FNS) of the lower-limbs has focused upon spinal cord-injured (SCI) subjects presumably because they lack a competent skeletal muscle pump and demonstrate poor afferent feedback from peripheral musculature (1). Davis and colleagues (2) observed that FNS is effective for inducing rhythmic contractions of paralyzed leg muscles, thereby "reactivating" the skeletal muscle pump and augmenting cardiovascular responses during arm crank exercise. Glaser et al. (3) have also demonstrated that FNS-induced contractions of the legs increased cardiac output and stroke volume at rest in able-bodied and SCI subjects. However, these previous studies have employed FNS-induced muscle contractions to attenuate venous pooling and augment central circulatory performance in postures of low orthostatic stress. Moreover, the mechanisms for increased stroke volume resulting from enhanced venous return (via FNS-induced muscle contractions) or increased heart rate (due to FNS activation of the vasomotor reflex) are not well understood in able-bodied individuals. Therefore, the **purpose** of the present study was to investigate the cardiovascular and metabolic effects of lower-extremity FNS in able-bodied subjects undergoing progressive orthostatic challenge by graded LBNP.

METHODS

Seven asymptomatic, able-bodied men (age = 26 ± 3 yr) were recruited for the present study. Following FNS habituation, the subjects underwent a progressive orthostatic challenge test in the supine position comprising graded lower body negative pressure at 0, -15, -30 and -45 Torr. At each level of orthostatic challenge, subjects experienced 7-min of lower body negative pressure (**LBNP**), followed by 7-min of LBNP with FNS-induced muscle contractions (**STATIC**). FNS-induced leg exercise consisted of rhythmic, asynchronous isometric contractions of hamstrings, quadriceps, gastrocnemius and tibialis anterior (5). Stimulation characteristics consisted of biphasic pulses of 0.3 msec width at 35 Hz, delivered through surface electrodes over the neuromuscular motor points (4). A duty cycle of 0.17 Hz (corresponding to 3 s on and 3 s off for each muscle group) was employed to ensure significant neuromuscular activation yet avoid possible interference with the subjects' intrinsic respiratory and cardiac cycles. The intensity of stimulation was adjusted to induce vigorous contractions in each muscle group below the maximum tolerable FNS pain level for each subject.

Cardiac output ($\dot{Q}$) during LBNP and STATIC were assessed via CO_2-rebreathing. Stroke volume (SV) was calculated from $\dot{Q}$ and heart rate (HR) derived from the subject's ECG. Steady-state oxygen uptake ($\dot{V}O_2$) was determined during open circuit spirometry and arteriovenous oxygen extraction ($a\text{-}\bar{v}O_2$ diff) was then calculated from $\dot{V}O_2$ and $\dot{Q}$. Blood pressures (SBP, DBP, MAP) were determined by optico-mechanical plethysmography on a beat-by-beat basis. The physiological data were analyzed using a two-way ANOVA to assess differences between conditions (LBNP versus STATIC) and across levels of orthostatic challenge (0 to -45 Torr). Differences of cardiovascular and metabolic responses were considered significant at the 5% level.

RESULTS

Cardiac outputs during FNS-induced leg contractions (STATIC) were significantly augmented over LBNP alone (by 1.02-2.05 $l \cdot min^{-1}$ at 0, -15 and -30 Torr; Figure 1).

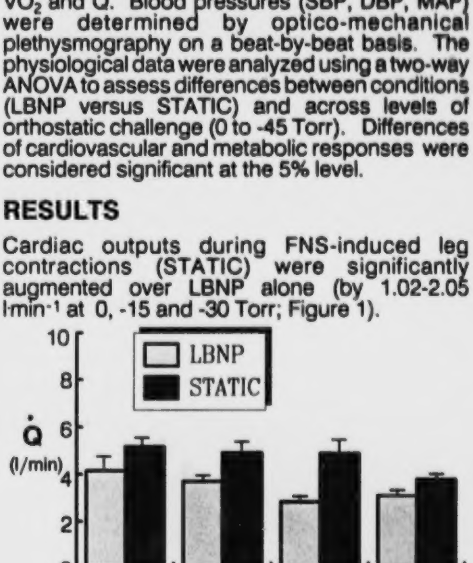

Figure 1. Cardiac output ($\dot{Q}$) during LBNP. Values are means ± SE.

The increases of $\dot{Q}$ were coincident with enhanced SV (by 6-31 ml·bt^{-1}, $p \leq .05$; Figure 2) and elevated HR (4-10 bt·min^{-1}). Steady-state $\dot{V}O_2$ was also increased over all levels of LBNP with the addition of FNS-induced contractions (mean increase=34%; $p \leq .05$), despite an unchanged a-$\bar{v}O_2$ diff.

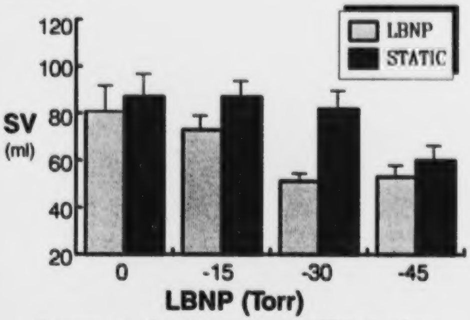

Figure 2. Stroke volume (SV) during LBNP. Values are means ± SE.

Although DBP was not altered by FNS, SBP was significantly elevated by 7-10 Torr during STATIC compared with LBNP. Thus, MAP was maintained during STATIC in the face of orthostatic challenge (mean increase=3.5-8.3 Torr over -15 to -45 Torr LBNP), primarily due to increased systolic blood pressure.

DISCUSSION

An important issue raised by previous researchers (1, 5) has been the extent to which circulatory hypokinesis arising from lower extremity venous pooling can be reversed by FNS-induced muscle contractions. This question has practical application both for SCI populations (wherein muscle paralysis or autonomic impairement may affect exercise capacity and physical performance) and for healthy, able-bodied individuals undergoing forced orthostatic challenge (eg. pilots performing G_z^+ maneuvers). In paraplegics, there exists suggestive evidence for the hypothesis that FNS-induced muscular contractions "reactivate" the peripheral muscle pump thereby augmenting venous return and increasing stroke volume under conditions of seated arm cranking (2), upright tilting (5) or upright posture with arm crank exercise (6). In contract, there is less evidence for a similar anti-orthostatic effect in able-bodied subjects. The major findings of this study were a marked enhancement of $\dot{Q}$ during progressive orthostatic stress (LBNP) consequent upon augmented SV and increased HR during FNS-induced leg contractions (STATIC).

Under LBNP challenge ranging from 0 to -30 Torr, $\dot{Q}$ was significantly increased by 25%-73% (1.02-2.06 l·min^{-1}) corresponding to a similar proportionate increase of steady-state $\dot{V}O_2$. Augmented $\dot{Q}$ could be attributed both to increased SV (by 13%-61%) and elevated HR. These data are generally consistent with observations of Glaser and colleagues (3) who reported 12-20% increases of SV and $\dot{Q}$ in able-bodied men undergoing pulsed FNS muscle stimulation in the sitting and supine postures. Both our earlier work with SCI subjects (2, 5, 6) and the present study support the view that cardiovascular performance may be significantly enhanced by FNS-induced pulsatile isometric contractions which "reactivate" the skeletal muscle pump to produce an enhanced venous return from peripheral compartments. On the other hand, the observation of an increased HR in our able-bodied subjects suggests that FNS may also produce a general sympathetic activation arising from stimulation of group III and IV afferents leading to a cardiogenic effect. This finding is inaccordant with Glaser and co-workers (3) who did not demonstrate elevated HR in their able-bodied men. Finally, neither increased HR via widespread sympathetic activation nor augmented stroke volume resulting from enhanced venous return were sufficient to significantly elevate $\dot{Q}$ or SV at -45 Torr. This may reflect the inability of FNS-induced muscle contractions to empty the venous pool under conditions of high orthostatic stress.

CONCLUSIONS

Augmented central hemodynamic responses during FNS-induced isometric leg contractions suggests that circulatory hypokinesis due to progressive orthostatic challenge (LBNP) may be partially reversed by FNS-reactivation of the skeletal muscle pump (through increased venous return) and/or an increase of general sympathetic tone.

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13.2

PEAK HEMODYNAMIC RESPONSES OF SCI SUBJECTS DURING FNS LEG CYCLE ERGOMETRY

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ABSTRACT

The purpose of this study was to compare initial pretraining peak central hemodynamic responses of spinal cord injured (SCI) quadriplegics (quads) and paraplegics (paras) during electrically induced leg cycle ergometry. Nine quads and nine paras exercised on an ergometer employing functional neuromuscular stimulation (FNS) of paralyzed leg musculature. Mean peak power outputs (POs) achieved were 9.5 W for quads and 14.9 W for paras. In comparison to rest values for quads and paras respectively, these POs increased oxygen uptake ($\dot{V}O_2$) by 268 and 283%, cardiac output ($\dot{Q}$) by 127 and 146%, stroke volume (SV) by 31 and 85%, heart rate (HR) by 53 and 33%, and mean arterial pressure (MAP) by 17 and 20%. Peak $\dot{Q}$, SV and MAP of paras were significantly higher (by 23-30%) than those of quads. These higher hemodynamic responses for paras may be due in part to their higher PO and $\dot{V}O_2$ levels. It thus appears that FNS leg cycle ergometry elicits a marked cardiac volume-load in SCI subjects which can be conducive for cardiovascular training. Physiologic responses to this mode of exercise would be expected to increase as peak PO capability increases with training.

INTRODUCTION

Arm exercise training has traditionally been used to promote physical fitness in SCI individuals with paralyzed lower-limb muscles. However, leg exercise may be more effective for cardiopulmonary (aerobic) training due to the larger active muscle mass and a greater volume-load on the heart (1). Leg cycle ergometers, driven by electrically induced contractions of paralyzed leg muscles, are now commercially available for the SCI population. Initial physiologic studies indicate that this exercise mode can substantially increase aerobic metabolism, pulmonary ventilation, and heart rate (2). However, fewer data are available to document the central hemodynamic responses to FNS cycling that may induce beneficial long-term cardiovascular adaptations (3,4,5,6). Therefore, the purpose of this study was to document and compare initial pretraining peak central hemodynamic responses of SCI quads and paras during FNS leg cycle ergometry.

METHODS

__Subjects__. Nine quadriplegic and nine paraplegic SCI individuals with lesion levels between C5 and T11 volunteered to participate in this study. Subjects were habituated to FNS cycle ergometry, but had not undergone formal training. Each group included two women and seven men, and a mixture of neurologically complete and incomplete SCI subjects. Neither group differed significantly for mean age (30 yr), height (179 cm), mass (70 kg), nor time since injury (7 yr). Prior to this study, all procedures were approved by the IRB of Wright State University.

__Procedures__. An FNS cycle ergometer (Model "ERGYS 1," Therapeutic Technologies Inc., Ft. Lauderdale, FL) was used in this study. FNS of paralyzed leg muscles was accomplished with rectangular-wave monophasic pulses (30 Hz, 0.375 msec duration, up to 130 mA current) delivered via skin surface electrodes over motor points of the quadriceps, hamstring, and gluteal muscle groups. Subjects performed a discontinuous graded exercise test from rest to muscle fatigue. Exercise stages were 5 min in duration, followed by 5-min rest periods. Power output was incremented by 6.1 W per stage. $\dot{V}O_2$ (STPD, L/min) was continuously monitored by open-circuit spirometry. SV and HR were assessed with impedance cardiography; arterial blood pressures were determined by auscultation; $\dot{Q}$, MAP, and total peripheral resistance (TPR) were calculated. All data are mean peak physiologic responses obtained during the final minute of exercise before fatigue. The data were statistically analyzed with analysis of variance and two-tailed independent *t*-tests with alpha = .05.

RESULTS

Table 1 provides the mean peak PO, $\dot{V}O_2$, and hemodynamic responses for each group. Although the mean peak PO achieved by paras was 5.4 W (57%) greater than that of quads, mean peak $\dot{V}O_2$ was only 0.11 L/min (14%) greater. These differences between the groups were not statistically significant due to the relatively large within-group variability of the data. In both groups, all hemodynamic responses increased significantly from rest to peak exercise PO. In comparison to rest values for quads and paras respectively, peak FNS cycling increased $\dot{V}O_2$ by 268 and 283%, $\dot{Q}$ by 127 and 146%, SV by 31 and 85%, HR by 53 and 33%, and MAP by 17 and 20%. Mean peak HR and TPR were not significantly different between groups. However, mean peak $\dot{Q}$, SV, and MAP of the para group were significantly higher than those of the quad group by 23-30%.

DISCUSSION

The low absolute peak PO attained by the SCI subjects in this study and the relatively high $\dot{V}O_2$ values elicited are comparable to those previously reported for SCI subjects during FNS leg cycle ergometry (3,4,5). This supports our previous observations of low exercise efficiency (i.e., high aerobic energy requirements for low rates of external work) for FNS-induced exercise (2,3).

Although elevated systemic $\dot{V}O_2$ is an important prerequisite for aerobic conditioning, the ability to increase $\dot{Q}$ is also a crucial factor. Exercise increases the cardiac volume-load, HR, and myocardial contractility, thus enabling the heart to pump blood at a higher rate. This type of cardiovascular stress is desirable and necessary to induce beneficial adaptations of the myocardium and ventricles (7,8). The present study demonstrates that FNS leg cycle ergometry can elicit significant increases in $\dot{Q}$ in both paras and quads. While the mean peak $\dot{Q}$ for our untrained SCI subjects increased about 2.8-fold over the resting value, it was

Table 1. Comparison of Mean ± SE Peak Responses of SCI Quadriplegics and Paraplegics During Rest and Peak FNS Leg Cycle Ergometry.

	Quadriplegics (n=9)		Paraplegics (n=9)		Δ	Δ	
	Rest	Peak	Rest	Peak	Peak	Peak (%)	
PO (W)	—	9.5 ± 1.8	—	14.9 ± 2.7	+5.4	+57%	
$\dot{V}O_2$ (L/min)	0.22 ± 0.03	0.81 ± 0.07	0.24 ± .01	0.92 ± 0.14	+0.11	+14%	
$\dot{Q}$ (L/min)	3.34 ± 0.22	7.58 ± 0.43	4.02 ± 0.22	9.87 ± 0.96	+2.29	+30%	*
SV (ml/bt)	62 ± 6	81 ± 5	54 ± 3	100 ± 7	+19	+24%	*
HR (bpm)	57 ± 3	97 ± 5	75 ± 4	100 ± 9	+3	+3%	
MAP (mmHg)	70 ± 5	82 ± 5	87 ± 3	104 ± 6	+22	+27%	*
TPR (mmHg/L/min)	21.0 ± 2.6	10.9 ± 1.0	21.9 ± 0.8	11.1 ± 1.0	+0.2	+2%	

* Significant differences ($p<.05$) between mean peak responses of each group.

substantially below that commonly found for able-bodied individuals during maximal-effort voluntary leg cycling (about 5-fold over the resting value). Therefore, we hypothesize that FNS cycle ergometer training with this degree of cardiac volume-loading is sufficient to reverse some of the obligatory myocardial atrophy and functional decrement following SCI. However, peak physiologic responses to FNS cycling would be expected to increase as peak PO capability with training.

Considering the severely impaired cardiac sympathetic innervation in quadriplegics, the lack of difference in HR responses between the paras and quads was unexpected. The relatively low (in comparison to able-bodied individuals) mean peak HRs of 97-100 bpm during FNS cycling suggests low sympathetic stimulation and/or high parasympathetic influence on the SA node of the heart. The peripheral nature of FNS may not stimulate full sympathetic control of the heart. However, limited cardioacceleration may allow more effective ventricular filling during diastole, and thus enhance ventricular preload, myocardial performance, and SV. Venous return and SV may also be facilitated during FNS cycling by the repetitive compression of leg veins by knee and hip joint movements and FNS-induced contractions of thigh and hip muscles. Conversely, high cardiac preload may have contributed to the relative bradycardia during FNS cycling by exciting the parasympathetically mediated baroreflex mechanism.

The most distinct physiologic difference between the paras and quads was the minimal pressor (MAP) response to FNS cycle ergometry among quads, another finding consistent with sympathetic impairment. The similar decline of TPR in both groups suggests arterial vasodilation in an equivalent mass of exercising muscles in response to FNS and local accumulation of metabolites. The quads, however, demonstrated a relatively low arterial blood pressure with the lowering of TPR. This limited pressor response to FNS exercise may be due in part to marked cardiovascular deconditioning and low $\dot{Q}$ response in these subjects. This situation may be reversed with regular FNS leg cycling exercise training. In untrained quads, however, an inadequate pressure response may be a critical factor limiting peak $\dot{Q}$ since $\dot{Q}_{max} = MAP_{max} / TPR_{min}$ (9). Limited peak $\dot{Q}$ can limit blood flow to active muscles, VO_2, and PO capability during this FNS exercise. The precise mechanisms controlling the interrelationship of blood pressure and $\dot{Q}$ in quads are currently unknown.

CONCLUSION

FNS leg cycle ergometry elicits marked metabolic and central hemodynamic responses in SCI subjects that are most likely conducive to long-term cardiovascular training effects. Initial peak $\dot{Q}$, SV and MAP of paras may be higher in absolute magnitude than those of quads, but quads may achieve a relatively greater cardiovascular training effect if they are more deconditioned.

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PHYSIOLOGIC RESPONSES TO SIMULTANEOUS VOLUNTARY ARM CRANK AND ELECTRICALLY-STIMULATED LEG CYCLE EXERCISE IN QUADRIPLEGICS

13.3

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ABSTRACT

This study examined physiologic responses in 8 quadriplegics performing arm crank exercise (ACE) alone, functional neuromuscular stimulation (FNS) leg cycle ergometry alone, and FNS cycling concurrent with ACE (HYBRID). FNS cycling was conducted on a Therapeutic Technologies Inc. "ERGYS 1" ergometer and arm cranking on a Monark Rehab Trainer™. HYBRID exercise elicited significantly higher oxygen uptake, minute ventilation, heart rate, and cardiac output and significantly lower total peripheral resistance than ACE or FNS cycling alone ($p < .05$). Stroke volume (SV) was similar between HYBRID and FNS cycling alone, and significantly higher than that elicited during ACE alone. These data demonstrate that HYBRID exercise, which involves a larger active muscle mass and higher total power output, creates a greater metabolic demand and cardiac volume-load than either FNS cycling or ACE alone. The results also support the view that FNS cycling and HYBRID exercise diminish lower-limb venous pooling in quadriplegics, and that HYBRID exercise will probably provide more optimal cardiorespiratory training benefits for paralyzed patients.

INTRODUCTION

Traditional rehabilitation programs have prescribed upper body exercise for the improvement of health and fitness in spinal cord injured (SCI) individuals with lower-limb paralysis. However, recent advances in functional neuromuscular stimulation (FNS) technology enable SCI to perform leg cycle ergometry and utilize a relatively larger muscle mass during exercise (9,10). Unfortunately, the exercise capacity attained and energy cost of FNS cycling may be limited due to (1) the deteriorated condition of the paralyzed muscles (11), and (2) inadequate organ-system adjustments to FNS exercise resulting from the peripherally-induced contractions and impaired autonomic sympathetic nervous system function in SCI (7).

To further augment the active muscle mass, energy cost, and sympathetic outflow in SCI persons during exercise, voluntary arm crank exercise (ACE) with concurrent FNS leg exercise (HYBRID) has been suggested (6,7). It has also been speculated that ACE with concurrent FNS leg cycling will increase the training capability of SCI persons above that which may be attained with ACE or FNS cycling alone (6,7). To date, there has been little research evaluating the physiologic responses to simultaneous FNS cycle and voluntary ACE (6). Therefore, this study examined the physiologic responses of SCI individuals to ACE alone, FNS cycling alone, and HYBRID (FNS cycle plus arm crank) exercise.

METHODS

Eight (7 male, 1 female) SCI individuals (mean ± SE: age = 24.2 ± .4 yr, body mass = 70 ± 1 kg) participated in the study. All subjects were quadriplegic (C5 - C8/T1), with 6 having complete lower-limb motor loss.

Each test session consisted of rest (5 min), followed by ACE (10 min), followed by rest (10 min), followed by FNS cycling (10 min), immediately followed by concurrent FNS cycling and ACE (10 min). Arm cranking was performed on a Monark Rehab Trainer, and FNS exercise was conducted on an ERGYS 1 cycle ergometer (Therapeutic Technologies Inc., Fort Lauderdale, FL). Surface electrodes were placed over motor points of the quadriceps, hamstring, and gluteal muscle groups. Cyclic FNS patterning was controlled by a microprocessor within the FNS cycle ergometer. Pedalling cadence was targeted at 50 rpm, and power output (PO), which ranged from 0-30 W during ACE and 0-12.2 W during FNS cycling were selected to approximate 50% of ACE peak PO, and the highest PO that could be maintained during 20 min of FNS cycling. Oxygen uptake ($\dot{V}O_2$), and minute ventilation ($\dot{V}_E$) were determined with open-circuit spirometry, and heart rate (HR) was monitored via ECG. Left ventricular stroke volume (SV) and cardiac output ($\dot{Q}$) were estimated noninvasively with transthoracic impedance cardiography. Arteriovenous oxygen extraction ($a\text{-}\bar{v}\ O_2$ diff) and total peripheral resistance (TPR) were calculated.

The data were statistically analyzed with one-way analysis of variance with repeated measures and Tukey's post-hoc tests. Differences were considered significant at $p < .05$.

RESULTS

Mean steady-state values for each physiologic response are listed in Table 1. Each variable studied, except for SV, was significantly increased above the value at rest during ACE alone, FNS cycling alone and HYBRID exercise. Stroke volume was not appreciably altered under conditions of ACE alone, but was significantly higher than rest during FNS cycling alone and HYBRID exercise.

FNS cycling and ACE alone elicited $\dot{V}O_2$, $\dot{V}_E$, HR, $a\text{-}\bar{v}\ O_2$ diff, and TPR responses which were not significantly different. $\dot{V}O_2$, $\dot{V}_E$, and HR were significantly higher and TPR significantly lower during HYBRID than FNS cycle and ACE alone. $(a\text{-}\bar{v})\ O_2$ diff was similar during HYBRID and ACE alone, and significantly higher during HYBRID than FNS cycling alone. FNS cycling alone and HYBRID exercise elicited similar SV levels which were both significantly higher than SV determined during ACE alone. Although there was a trend for higher $\dot{Q}$ during FNS cycling than ACE alone, the difference was not significant. $\dot{Q}$ during HYBRID exercise was significantly higher than during either FNS cycling or ACE alone.

DISCUSSION

As indicated by the significantly higher $\dot{V}O_2$ during HYBRID than ACE alone, the contribution of FNS cycling exercise to total metabolism is substantial. These results are in agreement with $\dot{V}O_2$ data previously reported for one paraplegic subject (6), and demonstrate that HYBRID exercise involving FNS cycling can increase $\dot{V}O_2$ and total PO to a greater extent than HYBRID exercise consisting of either FNS knee extension (1,8) or FNS static leg contractions (3). The marked elevation of $\dot{V}O_2$ during HYBRID exercise in this study is probably the

Table 1. Physiologic responses during rest and each exercise mode. Values are mean ± SE.

	Rest	Arm Crank	FNS Cycle	HYBRID
$\dot{V}O_2$ ($l \cdot min^{-1}$)	.23 (.01)	.66 (.02)	.65 (.02)	1.02 (.02)[a]
$\dot{V}_E$ ($l \cdot min^{-1}$)	10.0 (0.2)	25.9 (0.7)	26.5 (0.7)	39.7 (0.8)[a]
HR ($b \cdot min^{-1}$)	66.0 (1.8)	98.6 (1.6)	88.1 (1.7)	117.4 (1.0)[a]
$a\text{-}\bar{v}O_2$ diff⁺	6.1 (0.2)	10.7 (0.3)	8.8 (0.3)	11.2 (0.3)[b]
TPR*#	17.9 (0.2)	10.9 (0.2)	9.1 (0.1)	7.2 (0.2)[a]
SV ($ml \cdot b^{-1}$)	62.9 (3.0)	56.7 (3.4)[c]	68.6 (2.9)	80.0 (1.7)
$\dot{Q}$ ($l \cdot min^{-1}$)	3.88 (.13)	6.40 (.20)	7.64 (.20)	9.39 (.20)[a]

⁺ ($ml \cdot 100ml^{-1}$) *N = 5 # ($mmHg \cdot l^{-1} \cdot min^{-1}$)

[a] significantly different from FNS cycle and ACE

[b] significantly different from FNS cycle exercise

[c] significantly different from FNS cycle and HYBRID exercise

result of a relatively large active muscle mass and increased frequency of FNS contractions (50/min) (6). Considering that $(a\text{-}\bar{v})O_2$ diff was similar between HYBRID and ACE alone, the higher $\dot{V}O_2$ during HYBRID exercise was primarily a function of increased blood flow and oxygen delivery to exercising muscles. This is confirmed by the elevated $\dot{Q}$ during HYBRID exercise. The capacity for paralyzed skeletal muscle to extract circulating oxygen may be hindered by biochemical and structural changes that occur in muscle with disuse atrophy (11).

The higher $\dot{Q}$ during HYBRID exercise was due to a combined effect of significantly larger increases in HR and SV and a larger decrease in TPR during HYBRID than ACE alone. The increases in $\dot{Q}$ (47%) and SV (22%) above ACE during HYBRID exercise in this study are higher than the increases in $\dot{Q}$ (7-16%) and SV (10-19%) above ACE during HYBRID exercise utilizing FNS static leg contractions (3,4). The augmented SV during HYBRID exercise and FNS cycling alone supports previous speculations that FNS-induced leg exercise will prevent or reverse peripheral pooling and enhance venous return of blood to the heart (3,5,6,7).

The larger cardioacceleration during HYBRID exercise may be attributed to greater withdrawal of autonomic parasympathetic tone, and/or enhanced activation of the autonomic sympathetic nervous system. Due to the relatively low HR elicited in this study, it is difficult to ascertain which mechanism may be more influential to the observed cardioacceleration. Further clarification of this issue can be established by examining circulating catecholamines during HYBRID, FNS cycling alone, and ACE alone. A larger degree of arterial vasodilation and a corresponding decrease in TPR occur during exercise as more muscle mass becomes active. Impairment of efferent sympathetic pathways in SCI persons hinders peripheral vasoconstriction in metabolically inactive regions which also favors a decline in TPR during exercise (2). However, the fall in TPR decreases cardiac afterload which can enhance SV and $\dot{Q}$.

CONCLUSIONS

In conclusion, the physiologic alterations induced by concurrent FNS leg cycling, and ACE create a significantly higher metabolic demand and cardiac volume-load than either voluntary ACE or FNS cycling alone. These data support the view that FNS leg cycling plus ACE may provide for markedly greater cardiorespiratory training benefits for quadriplegics than traditionally prescribed ACE alone. Additional research documenting the central and peripheral hemodynamic adaptations to HYBRID (FNS leg cycling plus ACE) training regimens is needed.

ACKNOWLEDGEMENT

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FUNCTIONAL NEURAL STIMULATION IN STROKE REHABILITATION

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ABSTRACT

Since the 1960s much effort has been applied to implementing functional neuromuscular stimulation (FNS) as an adjunct to stroke rehabilitation. Yet, few systems are in use today. Experience in this center included 20 stroke and head injured individuals varying from community walkers to exercise walkers. Devices have included the Functional Electrical Peroneal Brace or Assist (FEPB/FEPA), the NeuroMuscular Assist (NMA), and the Case Western Reserve University (CWRU) percutaneous system. Stroke individuals and their caretakers had problems properly placing external stimulating electrodes. Those who could use the devices demonstrated (1) a short-term improvement in walking pattern which lasted up to three days following three weeks of daily use and (2) a general improvement in walking pattern which appeared to be permanent.

INTRODUCTION

Since Liberson[1] first demonstrated the use of FNS for footdrop correction, rehabilitation specialists have imagined the total correction of stroke gait defects using FNS. Several external systems were developed including those in Italy[7] and Yugoslovia[2,3,4]. Some of these were applied to large numbers of individuals but none became a standard treatment method. Medtronic, Inc., in conjunction with Rancho Los Amigos Rehabilitation Hospital, built an implantable version called the NeuroMuscular Assist (NMA)[9] which was tried in a number of centers including CWRU. The pre-existing CWRU percutaneous stimulation system was then utilized to provide multichannel-stimulation.

METHODS

All subjects other than those for the percutaneous system had been standard bilateral double upright AFO wearers prior to the studies. All subjects had stable function without neurological improvement for about six months. Table 1 outlines the basic systems studied. The FEPA/FEPB was studied as part of a national evaluation under the Committee on Prosthetic Research and Development of the National Academy of Sciences. The NMA was part of a national study in conjunction with Rancho Los Amigos and the percutaneous systems were an extension of the existing CWRU upper extremity technology[8].

RESULTS

None of our patients chose to continue with the surface stimulation systems - FEPB/FEPA. There were too many frustrations with electrodes and equipment when compared with the amount of gain from the device. A "carryover" effect was noted with an improved gait pattern persisting for half a day to three days after FNS use. Although the implanted single-channel system was much more acceptable to the patients, all but one eventually developed sufficient improvement to walk, at least part of the time, with no brace. The biggest problem with these implanted systems was their inability to control the hip and knee. Most subjects preferred to wait until knee control was available before submitting to implantation. The multi-channel percutaneous systems allowed an essentially unlimited choice of muscles but had the problem of electrode care and were thus unsuitable for permanent use.

DISCUSSION

The "carryover" effect lasting for about half a day to three days was an expected although not totally explained phenomenon. This had been well-described in earlier work at CWRU and elsewhere[1,6]. The fact that the NMA subjects tended to reject all braces was not expected. Even though all subjects were at least two years post stroke and had been stabilized for some time, there is no question that most demonstrated definite improvement in function. Whether this was function that had been present but hidden prior to the study or whether the constant reinforcement of the stimulation actually facilitated the development of new central control pathways is not known. This trend is appearing also in the new applications to more involved stroke individuals who are using multichannel stimulators with

TABLE 1

#	DEVICE	PLUS ASPECTS	MINUS ASPECTS
8	FEPA/ FEPB	corrected footdrop well	electrode placement; wire placement; wire breakage; equipment malfunction
7	NMA	corrected footdrop well, easy to use	one-channel limit; equipment malfunction
5	CWRU	corrected multiple gait defects	percutaneous wires; equipment malfunction

percutaneous wires. Controlled studies to better understand this are underway.

CONCLUSION

Unexpected improvement in unbraced function in previously stable stroke and head injury individuals was found. This appeared to remain after cessation of stimulation.

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PERCUTANEOUS FNS IMPLEMENTATION TO IMPROVE AMBULATION IN STROKE SUBJECTS

13.5

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ABSTRACT

We have developed a method to implement a percutaneous functional neuromuscular stimulation (FNS) system which includes patient selection and evaluation, electrode implantation, muscle exercise, programming and evaluation of functional ambulatory tasks. This is an iterative process designed to maximize the subject's immediate function. The process is continued as long as it is mutually agreable to the subject and the research staff that the subject can attain additional function by further participation.

INTRODUCTION

Functional neuromuscular stimulation has long been shown to either provide or improve residual function in paralyzed individuals. In our laboratory at the Cleveland Veterans Administration Medical Center we have developed over the years a process of percutaneous FNS system implementation which emphasizes maximum improvement of ambulatory functions. This is accomplished by implantation of electrodes to control as many muscles as necessary to achieve functions that appear normal and that require minimal effort on the part of the subject. In this paper we report on application of this method to two paralyzed individuals who suffered cerebrovascular accidents (CVA).

METHODS

Our method of percutaneous FNS system implementation, shown in Figure 1, is designed to maximize the immediate function that a subject can attain from his/her participation in the program. Subject selection is based on both physical and psychological evaluation. This is done, first, to assure that the subject's paralyzed muscles can be stimulated and second, to assure that he can cope with both the rigorous physical efforts required in the early stages of system implementation and the disappointments of unfulfilled expectations.

Intramuscular percutaneous electrodes are implanted in the muscles to provide maximal additional function to the subject. For example, if the subject is unable to stand because of paralyzed knee extensors then the quadriceps muscles would be implanted first. However, if he is able to stand, as is the case in most stroke patients, but is unable to walk because he lacks hip flexion, then the first implants would be in the iliopsoas, sartorius, tensor fasciae latae and gracilis.

The implanted electrodes are monitored for electrical impedance to prevent stimulation through a broken electrode which may cause tissue damage. An electrode is removed if it exhibits high impedance. A new electrode is then implanted and the muscle is exercised with electrical stimulation for at least an hour a day. Function and strength are evaluated on a regular basis through manual strength tests and dynamometer (Cybex) measurements. If the function is of sufficient strength to produce a movement about the respective joint against gravity or against resistance, the muscle is then included in functional stimulation patterns for standing, stepping, walking, ascending and descending stairs and other activities. If sufficient strength is not achieved in about a month, then additional electrodes are implanted in the same and in synergistic muscles to attain desired function.

Template patterns of different functional activities have been developed and can be easily tailored to a particular individual. These are transferred to their portable stimulators and included in the menu of activities to complement their residual function.

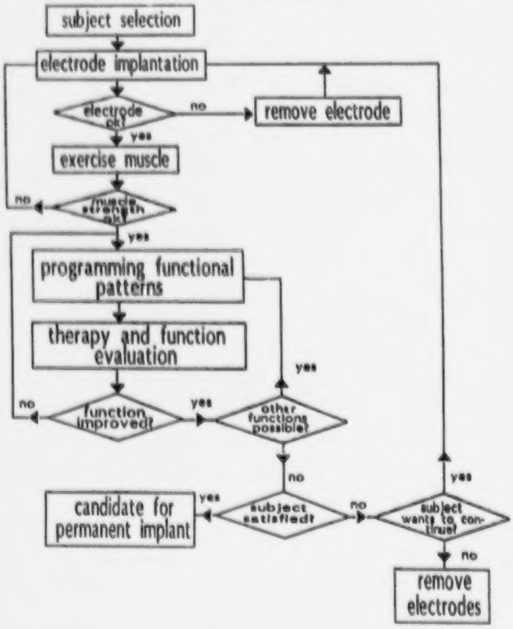
After programming for functional activity, subjects undergo therapy and functional evaluation. Therapy involves learning to coordinate their residual function with that provided by stimulation during various functional tasks. Evaluations are based on video tape recordings, kinematic data from a motion analysis system, metabolic measurements and the subject's perception of the ease with which he performs a task.

Programming modifications are made continuously, based on evaluations to optimize the function. If function can be improved by implantation of additional electrodes, then the loop in the diagram is repeated, provided that the subject is satisfied with the progress and is willing to undergo further development of his electronic orthosis. If at any time or for any reason the subject wants to terminate his involvement in the project, then his electrodes are removed and he is free to leave. Otherwise, he may be a candidate for a permanent implantable system if both he and his physician agree that the benefit/risk ratio is high and the additional function provided by the FNS system significantly increases his mobility and independance in daily living.

RESULTS AND DISCUSSION

Using this method we achieved walking in one CVA subject who had total absence of motor function on the left side of his body. After he had gone through a conventional physical therapy program, he was able to stand in parallel bars wearing a knee-ankle-foot-orthoses and make a couple of steps only by maneuvering his upper body. With the percutaneous FNS system, he can now walk repeatedly a distance of up to 80 feet at a time using either a walker or quad cane. Electrodes were implanted in the following order; in his quadriceps for knee extension; sartorius, tensor fasciae latae and gracilis for hip flexion; tibialis anterior and peroneus longus for dorsi flexion; gluteus maximus, posterior portion of adductor longus and hamstrings for hip extension; short head of biceps for knee flexion; and gluteus medius for mediolateral hip stability. Additional implantation of electrodes planned for this subject are in iliopsoas to improve hip flexion; paraspinal muscles of the lower back to improve hip/trunk extension; and gastrocnemious and soleus to provide him with push off during walking. In another CVA subject with reduced coordination and muscle weakness on his right side we were able to achieve a more normal appearing gait. Without FNS this subject walks with circumduction of his involved extremity and hikes on his left foot to clear the circumducting leg. FNS has provided him with additional hip and knee flexion resulting in a more normal appearing swing which obviates the need for hiking. Improved gait has been achieved by implantation of quadriceps, iliopsoas, sartorius, tensor fasciae latae, gracilis, hamstrings, short head of biceps, tibialis anterior and peroneus longus. Additional improvements will include plantar flexors for push off.

PERCUTANEOUS FNS IMPLEMENTATION



CONCLUSION

We have developed a process of percutaneous FNS system implementation which emphasizes immediate gain in subject's function. It allows him to be an active participant in evaluation of his progress and in planning the course of further actions towards improved mobility and independence.

This system has been applied to subjects with complete and partial paralysis due to spinal cord injury and stroke with significant improvement in their function.

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GAIT EVALUATION OF HEMIPARETIC PATIENTS USING SUBCUTANEOUS PERONEAL ELECTRICAL STIMULATION

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ABSTRACT

A long term follow-up of the gait pattern of hemiparetic patients using implantable peroneal stimulators for drop foot correction has been analysed. Gait parameters and EMG activity of subcutaneously stimulated muscles were measured and compared with the results obtained before implantation as well as its variation during time. Nineteen from the population of 32 patents with previously implanted electrodes were evaluated. In 15 patients corrected gait was good and in five less satisfactory.

INTRODUCTION

Since 1981 to 1988 32 hemiparetic patients have had a peroneal underknee electrical stimulator implanted in Ljubljana (1). During a minor surgical procedure, the peroneal nerve electrode position was selected by moving the implant along the exposed common peroneal nerve, while monitoring EMG responses of the tibialis anterior, peroneus longus and soleus until good foot movement was obtained (2).

The benefits of functional electrical stimulation was assessed by measuring shoes (3) and electrogonograms. Gait pattern was assessed each year, following surgery,in an attempt to analyse the efficacy of the implantable stimulator over a longer period.

METHOD

The method of evaluation of gait consists of comparing foot response to stimulation pulses from the subcutaneous electrodes and the estimation of foot dynamics during gait with and without stimulation. Foot movement was described as rotation about the ankle joint axes in: dorsal-plantar flexion and eversion-inversion while simultaneously recording EMG activity of the tibialis anterior, peroneus longus and soleus.

Gait events on the point of action (POA) trajectory have been denoted as follows: Hc beginning of POA at heel contact, M midfoot area, while T represents the POA running through the toe off phase. If the trajectory of the POA runs on laterally or medially on the sole (out of the marked area), indices l or m are added to the standard notation, as shown in Figure 1. Comparison between attributes describing foot responses and gait dynamics are the measure of reliability of the electrode position and quality of gait control over time. For example, foot response described by dorsal flexion and moderate eversion (DF,m.EV) (active tibialis anterior and peroneus due to stimulation) and POA by Hc,M,T represents good gait and high correlation between gait and stimulation, while foot response characterised by eversion (EV) (active only peroneus) and POA by Hc,M,T has good gait and small correlation.

RESULTS AND DISCUSION

From the population of 32 implanted patients eight immlants were removed for different reasons. Three patiens died three years after implantation, one patient had leg amputation of a cause unrelated to the implants and four implants were removed due to patients pain sensation. Nineteen patients from the population of 24, daily used implants were analysed. Time domain analysis of the ground reaction pattern indicated two characteristic groups of trajectories: a) a tendency to approach a normal gait trajectory and b) following a period of stability in trajectories, eight patients exhibited migration of the trajectory to a new undesirable state, due to excessive eversion. In these patients reimplantation was necessary after an average of 3,5 years of good functioning. Following reimplantation, similar ground reaction patterns and foot responses were observed as following the initial implantation.

In Figure 1 gait of right hemiplegic patients, case 11, implanted in 1982, are shown. Dashed lines represent gait with subcutaneous stimulation while full lines represents gait without stimulation. Significant improvements of POA of impaired leg during gait with stimulation has occured. Foot response on stimulation pulses are described as DF,m.EV and is in good correlation with POA trajectory Hc,M,T. Thirteen patients have a good gait and high correlation between stimulation and gait correction while two patients have a good gait and low correlation. Gait parameters of these patients has also improved with stimulation. Gait velocity was raised for 20% (P<0.01), free gait cadence for 12% (P<0.02) and stride length for 10% (P<0.05) . The results are comparable with (4). The average time of implantat'on and follow-up was 4.3 years (range, 0.5 to 8 years)

The remaining five patients' gait have also been altered by FES but they are poor and have to be reimplanted.

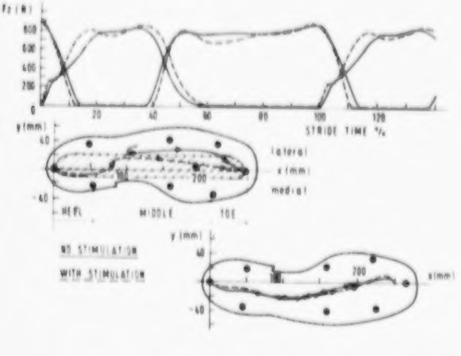

Fig. 1. Average ground reaction force and its POA of gait of a hemiplegic patient without stimulation (solid line) and with stimulation (dashed line).

From the observed population the following conclusion could be stated:

- with subcutaneous stimulation, when it is indicated, the gait performance could be achieved, at least as well as with surface stimulation,
- the characteristic of gait pattern caused by peroneal implants are reproducible over time,
- stability of gait pattern are dependant on electrode-nerve fixation.

Efficacy of the implanted stimulator may be improved by two channel implantible stimulator (4).

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DESIGN AND EVALUATION OF A VOCATIONAL DESKTOP ROBOT

14.1

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ABSTRACT

A desktop robotic assistant has been designed for vocational applications. This system allows quadriplegics to return to the workplace after their injury, and pursue jobs in a workstation setting without a full-time attendant to perform manipulation tasks for them. The increased independence enhances their quality of life, and the increased productivity justifies such a high-technology solution.

INTRODUCTION

There are over 67,500 quadriplegic individuals in the United States today; each year an estimated 2,400 to 6,000 new injuries result in quadriplegia [1]. These individuals have minimal or no functional use of their extremities and are completely dependent upon an attendant to perform daily activities. Most of these individuals are injured as young adults and live a normal lifespan. Severely disabled individuals, prospective employers, and third party payment agencies are mandating that the workplace be made more accessible to dis-abled employees, and that technology be used to reduce attendant care. The Palo Alto VA Rehabilitation R&D Center, in collaboration with the Spinal Cord Injury Center (SCIC), has designed a track-mounted robot system that works toward these goals. The system is being used at a local programming school by a high-level quadriplegic to access reading materials, operate the computer, and support his daily living needs.

BACKGROUND

Since 1981, four generations of voice-controlled Desktop Assistant Robots (DeVARs) have been developed at the Palo Alto VA. The first three generations have emphasized daily living activities such as meal preparation and feeding.[2] DeVAR-III has been evaluated by 25 high-level quadriplegics (C2 to C6) at the Palo Alto VA SCIC.

The user-interface software, computer hardware, robot arm and controller, and gripper are shared by DeVAR versions III and IV. DeVAR-IV is differentiated by the addition of the overhead track for the arm and the vocation-oriented applications.

Several other desktop robot systems are currently being developed in the U.S. for introduction to the market, notably at Georgia Institute of Technology and at Prab Command, Inc.

METHODS AND MATERIALS

System Configuration

The vocational workstation was built with Herman-Miller office furniture. The work area is set up in the form of a "U", with the robot suspended over the center of the desk (Figure 1). Equipment and appliances are placed on the side-worksurfaces and shelving. The arm can reach down to the desktop, out to the side shelves, and forward to the user. An adjustable keyboard-holder in front of the user carries a book holder, microphone, and a place for a lunch bowl.

The equipment for DeVAR-IV includes a Unimation PUMA-260 arm with a VAL-II controller. The arm is mounted on a 4' track with a 0.01" position resolution, and moves at up to 1'/sec. The gripper, an Otto-Bock Greifer, uses an internal linear encoder to measure hand opening (0.02" resolution). Both track and gripper use a 6-axis Q-bus controller card based on Hewlett-Packard HCTL-1000 DC-servo controller chips. Figure 2 shows a CAD drawing of several key DeVAR components. The robot control PC contains a VOTAN voice recognition and playback unit, an environmental controller for lights and appliances, a color monitor for the user and a monochrome monitor for programming and debugging.

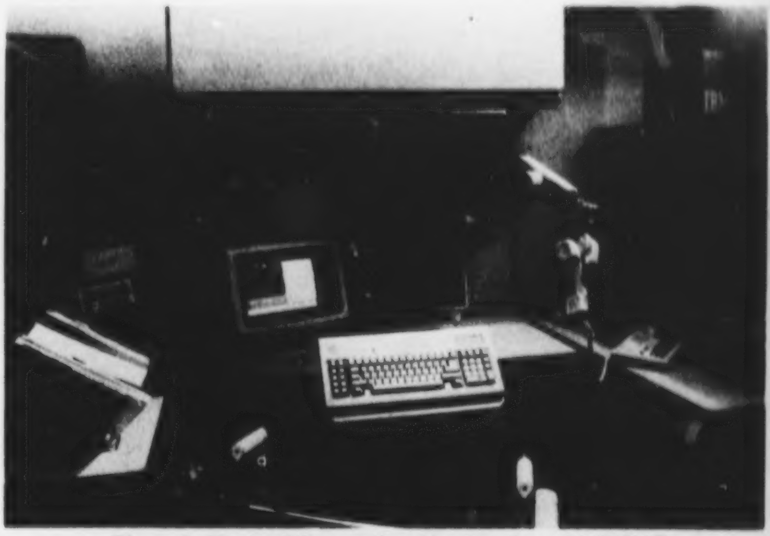

Figure 1. Photo of the vocational workstation with DeVAR.

Clinical and Field Evaluation Methods

The configuration of the desktop environment was developed from results of visits to the workplaces of three disabled individuals. The visits examined scheduling, workspace arrangement, and levels of dependence in vocational and daily living tasks.

Based on results of these evaluations, a site for the first field placement was chosen. Disabled Programmers Inc. (DPI), a non-profit computer programming school, has experience with both computer technology and the education of disabled individuals. A respiratory-dependent C3-4 quadriplegic student was trained to use DeVAR. The computer is programmed to record all voice commands and store them in a file for future reference and evaluation. In addition, the student's sessions are videotaped, primarily to monitor the voice recognition unit's performance. These two sources of real-time data allow a complete task analysis of the user and robot.

RESULTS

We have developed ten VAL-II routines for the office and daily maintenance needs of a quadriplegic user. The tasks were chosen based on the site-evaluations. Several modifications of the user I/O program, additions to the vocabulary, and new commands for control of the motorized track and the hand were made.

DPI placed a corner of their classroom at our disposal to install DeVAR. The set-up is complete, and the disabled student has been trained to use the system. He can answer the phone, serve himself lunch, operate the classroom computer, choose a floppy disk, and get out a manual. Based on his suggestions, we changed the design of the bookstand to make it easier for him to turn pages with his mouthstick. Applications soon to be completed include: handling computer printouts and music cassettes, dispensing medication, and accessing phone features by voice.

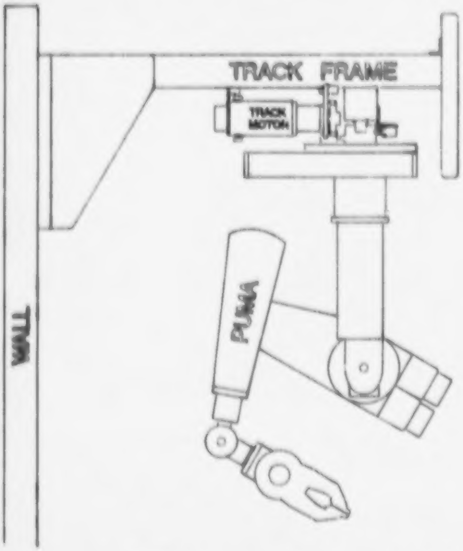

Figure 2. CAD drawing of a cross-section of the overhead track, showing the suspended PUMA-260 and Otto-Bock Greifer.

DISCUSSION

The vocational function of DeVAR represents a major step toward reducing health care costs and improving quality of life of severely disabled persons.

A track system increases by four the working volume of the PUMA-260 while maximizing safety for the user by keeping the size of the robot arm small. The use of the Herman-Miller landscape furniture allows individuals to customize their workplace and implement the robot track and arm as a single module.

The addition of sensor systems in the track and hand allow for safer and easier use, though they require more programming. For example, if a manual is absent, the robot will not continue its preprogrammed motions, but stop and tell the user of the problem.

CONCLUSIONS

The installation of a number of DeVARs in clinical and vocational settings will accelerate the diffusion of this technology and create a larger library of application programs for all users. The data gathered from installing DeVAR at DPI can promote the system's effectiveness in returning severely disabled persons to the workforce, and assist in convincing third-party payers of the usefulness and economic viability of robotic technology in the area of rehabilitation.

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Education and Research Issues in Designing Robotically-Aided Science Education Environments

14.2

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ABSTRACT

The design, development, and testing of robotically-aided educational environments has been ongoing since 1986 at The Ohio State University (OSU). Successive generations of robotic tools have resulted in a prototype hardware and software robotic system which has recently undergone four months of continuous field testing in a public school setting. This article will discuss certain aspects of the training and instruction developed to instruct physically disabled students in the use of this prototype system, and the research components designed as a part of the overall educational robotics project.

RELATED RESEARCH

The work of the Educational Robotics Laboratory at OSU in developing robotic assistive tools has focused specifically on the cognitive and academic impact of the use of robotic tools within an educational environment (1, 2, 3) . The specific content area selected as the focus for instructional development was science education and the instructional context chosen was the science laboratory workplace. The current status of these foci have been the completed design,development, and initial testing of a set of science-based educational activities that can be effectively implemented using a prototype robotic system. A sequenced set of 10 training activities and 22 science-education activities were implemented during the 1987-88 school year using an initial prototype robotic system.

TRAINING AND INSTRUCTION ISSUES

The design and development of instructional activities are of primary importance in establishing a robotically-aided workstation as an environment for educational and cognitive enhancement. The work at OSU has led to the conclusion that the most effective pattern for teaching a young, physically disabled student, given current technology limitations, is to first **train** the student in the use of the robot as a tool; and then to introduce science **education** concepts and skills in which the child uses the robot as an **aid** in manipulating objects within the educational environment. The primary issues facing this design team were the following contextual and educational issues: 1) the robotically-aided education environment, 2) the science education content, and 3) the instructional approaches needed to transfer knowledge.

Academic environments

The intention is to design and implement a model, robotically-aided environment that can be successfully integrated into the ongoing program of instruction in any elementary school setting. It is important that the eventual design result in a model system that can be integrated; that is, it must respond to such issues as overall reliability of the technology, cost effectiveness, ease of use and utility. An important affective goal of this research and development project involves the student developing feelings of control over the environment which we believe leads to self-efficacious behavior.

Science content

The focus of the science educational activities are the **processes of scientific investigation**, which are considered to be a valuable component of the overall educational goal of developing reliable inquiry skills. The instruments and materials of science provide a rich, exploratory environment that is highly manipulable. An attempt is made to use examples and activities from the physical and biological sciences that emphasize various aspects of the processes of scientific investigation. These activities are conducted and data analyzed with the resulting information being incorporated into the disabled student's overall academic experiences.

Instructional approaches

As previously mentioned, an important observation of the team was that the student needed to engage in a two-phased instructional process that involved initial training activities, and then the science education activities. The structure and meaning of the various activities within each of these two phases of the process are as follows:

The Training component. The primary goals of this component involve: 1) the development of motor competencies, 2) the development of cognitive automaticity and transparency of the technology, and 3) the development of a positive attitude and intrinsic motivation to continue working with such assistive devices. Training is required to integrate hardware functions and software capabilities available through use of the menu. It is also important to develop basic robot arm control skills that involve both control techniques and object manipulations. Finally, it is important to facilitate the student's communication skills since so many of this population also have significant communication disorders.

The Instructional component. The primary goals of this component involve: 1) the development of sound, defensible academic experiences, 2) strategies for the organization and analysis of scientific information, 3) a means for the synthesis and communication of ideas. Important instructional targets include developing the student's ability to observe, classify and measure objects and phenomena in the environment. The content focus of developing information about the process and procedures of science have been discussed, but also interact at this level of the design process. Finally, another focus of this component is the effective communication of ideas and experiences by the students.

RESEARCH PROCEDURES AND PRELIMINARY DATA

Research in the work performed with disabled students included pretest and posttest data on the development of automaticity in motor control skills and in qualitative descriptions of the interactional nature of the robotically-aided laboratory environment. Methods for data collection include field observations, interviews, the Space Visualization Test from the Southern California Sensory Integration Tests, the Single-Input Control Assessment from the Easter Seal

Communication Institute, and a motor control/cognitive mapping assessment.

The field based research has yielded several themes pertaining to those factors that influence the acceptability and usability of the robotic environment. These themes include training methodology, the transparency of the robotic system (the degree to which the technology itself is apparent to the user as he/she performs tasks), and curricular applications. Continuing data collection and analysis will solidify and/or modify the elements of each theme. The motor control/cognitive mapping test has yielded some interesting data regarding time/accuracy trade-offs and spatial processing. Each test requires progressively more difficult spatial processing but maintains the same motor control effort. Two measures are taken: 1) accuracy in pressing a switch on the input device that corresponds to a menu item on the computer monitor, and 2) time between the appearance of the stimulus and the press of the switch. This test will be given periodically over the course of the project. It is expected that accuracy will increase and time for completion will decrease. The third test reflects the development of cognitive mapping skills of the menu the students use while manipulating the robot. This arrangement simulates the robot, monitor, and input device working space. As the menu becomes better mapped in the students' minds, the students don't need to look at the monitor for the corresponding column. Time for completion in Test 3 will likely decrease more dramatically across time than in the other tests. Cognitive mapping also serves as an indication of technology transparency.

SUMMARY AND FUTURE DIRECTIONS

The research and development efforts of the educational robotics project at OSU have resulted in the development of an set of training and science instruction activities for use by elementary-aged, physically disabled students. In addition, specific research questions and the overall interactional nature of the educational robotics environment are being investigated during the course of this project. The current work with disabled students provides proof of the value of educational robotic environments as motivational settings, and has developed some initial data confirming their utility as educational tools. Finally, preliminary data indicates that student users mentally "automatize" the operational routines associated with using a robotic device and that this learning is remarkably resistant to decay over long gaps in training. A final reporting of the results of this year's research will be made available for the 1989 RESNA Annual Conference.

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- The Ohio State University, College of Education, Office of Research and Development Services.

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THE UT/HMMC ROBOTIC AID

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INTRODUCTION

The long term goal of the University of Toronto/Hugh MacMillan Medical Centre Robotic Aid Project is to develop a general purpose robotic aid for the severely physically disbled. Ideally, such a device should have the ability to work, if necessary, even in a completely unstructured environment and be able to safely and reliably perform any task the user might require.

This paper presents the work completed through phase I of the project. Specifically, it outlines the hardware and software features of the robotic aid system, and presents preliminary testing results from tests conducted in a clinical pilot study being carried out at Lyndhurst Hospital.

SYSTEM DESIGN

Hardware

The UT/HMMC Robotic Aid system consists of a U.M.I. RTX manipulator controlled by an IBM PC/AT compatible computer — the host computer — and interfaced to the user through a VOTAN speech recognition unit. Three Honeywell ultraminiature proximity sensors are mounted on the RTX's gripper. These sensors provide the feedback information for the object detection required by the automated grasping routine. Two of the sensors — diffuse scan sensors — are mounted at the gripper's fingertips and used to detect the presence of an object in front of the gripper. The third sensor — a thru-scan sensor — is mounted at the base of the gripper's fingers and is triggered when an object is located between the fingers.

All three sensors are wired through a bank of ten wires in the arm's wiring loom. These wires run from a socket in the wrist to an output socket on the RTX's connection panel. A ribbon cable carries the sensor signals to an I/O card in one of the host computer's expansion slots. The outputs from the sensors are TTL levels.

Software

From the outset of the project, it was specified that the robotic aid should be capable of operating in an unstructured environment. Consequently, the high level control software was designed to allow for direct control of the manipulator instead of pre-programmed control. Furthermore, since previous research efforts [1,2] have shown that requiring the user to guide the robotic aid step by step through a task leads to user fatigue and frustration, the UT/HMMC robotic aid is provided with an automated grasping capability in an attempt to reduce the tediousness involved in performing a task.

There are two modes in which the user can control the robotic aid: the primary control mode allows for task space (i.e. end effector) control of the robot while the secondary mode provides joint space control. Although task space control is an easier and more efficient control mode, individual joint control is included so that the user can maintain control of the robotic aid even if it loses its calibration during use. Since the task space control routine relies on the forward and inverse kinematic solutions to generate the end effector's trajectory, decalibration renders the routine ineffective. If the user is in the middle of a task when this happens, he/she can switch to joint space control to complete the task and then re-calibrate the RTX to regain task space control. Both, mode switching and arm calibration, can be carried out through voice commands.

Once the robotic aid has been brought, through task space (or joint space) commands, to the vicinity of an object to be grasped, the user can issue the **Grasp** command to invoke the automated grasping routine. The robot would then automatically scan a region to locate the object, center its gripper to that object and effect the grasp. Even though the process is automatic, the user can, at all times, interrupt the routine and regain direct control over the robotic aid.

User Interface

Since the interface is the only link between the user and the robot, it not only must be flexible and easy to use but must also place the user in total control over the robotic aid and provide a degree of safety and reliability to the system. To this end, a dynamic, menu driven screen display is used to complement the voice recognition unit as the control interface and to provide visual feedback in addition to the audio feedback from the speech unit. The screen display is dynamic in the sense that only those commands that the system will accept at that particular time are shown. In addition, a window on the screen is reserved for displaying the last recognized command. If an unacceptable command is issued, this window goes blank and an appropriate message is displayed on the screen.

The voice recognition unit is used to determine which commands are acceptable at any particular time. We have programmed the unit to restrict its search during recognition to prespecified subsets of the vocabulary. At any time, the active subset consists of the commands that are displayed on the screen. The voice recognition unit also provides audio feedback by echoing each command it recognizes.

RESULTS AND CONCLUSIONS

We are currently in the process of clinically testing the robotic aid. So far, only one subject (a C_5 quadriplegic) has been trained to use the robot. Preliminary testing of the robotic aid with this subject has yielded encouraging though inconclusive results. The testing involved using the robotic aid to grasp three different objects arranged on a bench near the robot. The subject was required to perform this task twice; first by using the automated grasping routine and, then, by directly controlling the robot to grasp the objects. The time required to complete the task was recorded. For both methods, the subject required approximately two and a half minutes to complete the task. However, during the direct control approach, the subject only managed to grasp two of the three objects; the third was knocked off the bench.

These results indicate that when the position of an object to be grasped can be clearly seen, both methods can be used to successfully effect the grasp and can do so in approximately the same time. On the other hand, when an object's position relative to the gripper cannot be clearly seen, the direct control approach often does not yield a successful grasp. In contrast, the automated grasping approach does yield a successful grasp.

FUTURE WORK

Testing has also revealed that, inspite of the automated grasping capability, direct control still imposes an unacceptably high control burden on the user. In an attempt to further reduce this burden, the next phase of the research will concentrate on developing a task oriented command language. In addition, the robotic aid will be given the capability of 'learning' tasks to be replayed later. The user will be able to modify these 'taught' tasks in real time.

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Hardware and Software Considerations in the Design of a Prototype Educational Robotic Manipulator

14.4

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ABSTRACT

The design, development, and testing of robotically-aided educational environments has been ongoing since 1986 at the Ohio State University (OSU). Successive generations of robotic tools have resulted in a prototype hardware and software robotic system which has recently undergone four months of continuous field testing in a public school setting. This article will discuss aspects of the hardware features developed for use with physically disabled students, and the software engineering issues designed as a part of the overall educational robotics project.

HARDWARE DESIGN ISSUES

Some of the most important general issues involved in the selection, adaptation, and use of hardware for educational robotic systems include the following:

Adaptability/Versatility: a) adaptable for use with a variety of disabilities; b) its operation is easily learned; 3) simple and comfortable access to input devices.

Mechanical/Electronic Integrity: a) incorporates a high-quality architectural design, b) well-constructed and integrated hardware system, c) accurate, extensive and well-organized documentation, d) parts are readily available.

Utility/Safety: a) the system must be capable of performing reliably and consistently in a variety of instructional settings, b) the system must insure the safety of the student user.

Aesthetics/Cost Effectiveness: a) the system must be acceptable in appearance, b) low cost adaptation can be made, c) reasonable total and operating costs.

HARDWARE SOLUTIONS

The selection of hardware was determined as a result of our experiences with an earlier prototype system using an Apple IIe, and Rhino RX-3 robot. A need for more sophisticated equipment with greater payload, speed and reliability led us to design and develop the current prototype system consisting of three major components: 1) an 80286-based MS-DOS computer (IBM PC-AT compatible), 2) the UMI-RTX robot arm, and 3) the Prentke-Romich arm-slot controller (5-switches). The basic rationale for selection of these systems were both for intrinsic capability and compatibility with other robotics research and development projects from throughout the world.

The decisions surrounding the robot were particularly important and resulted in the choice of the UMI-RTX system because the performance/cost ratio was judged to be superior to any other machines in the $10,000- $20,000 range. This gives the UMI a higher probability of becoming a viable, commercially-available tool that could find its way into the schools of the U.S. In addition, several major features are available that were lacking in the first prototype system: 1) an additional degree of freedom (wrist yaw); 2) force sensing (programmable), 3) program-selectable speed, and 4) a significantly larger payload (6 lbs.). A disadvantage of the UMI robot is its somewhat imposing size, especially for children in wheelchairs, but with careful design of the workspace -- the affect has been minimized.

The arm is mounted on a laminated desk (60" wide X 40" deep X 29" high). The top is a light, beige color which facilitates visibility across the entire workspace. The arm is mounted at the back of the desk so that it reaches only about two inches beyond the edge of the desk when fully extended and cannot enter the space of the wheelchair-bound student user. The large surface area of the table is in scale with the arm and provides space outside its work envelope for attaching tool holders and storage spaces. The system monitor is mounted on a swing arm so that it can be relocated easily for each student.

SOFTWARE DESIGN ISSUES

The philosophy of the software design team was to develop effective environmental interactions and feelings of empowerment in the learner through effective and efficient software control. The software solution was designed to provide easy, transparent access to the capabilities of the robotic tool. It was (and is) a complex problem that required critical input from members of the therapeutic, educational and engineering teams in order to utilize knowledge of the population characteristics to design the various control features in the software package. The design of such software is clearly an ongoing process that mirrors the evaluation information originating from the work in the elementary school.

SOFTWARE SOLUTIONS

The primary design goal was to utilize some of the available capabilities of the severely physically disabled students, including their considerable cognitive abilities and minimal physical control abilities, to understand and use the software via an adaptive input switch device. The problems facing the design team were threefold: 1) the students' disabilities required the software to be **easily accessed** and still maintain a **reasonable interactional speed**, 2) the **learner control features** must be understandable, powerful and complete, and 3) the conceptual, engineering, and mathematical problem of **defining the robotic motions** which would provide the most powerful interactional learning environment within the limitations of the particular robot arm.

Software Issue #1: Easy Access and Interactional Speed

Developing access to the robot through a software control interface was a difficult conceptual and engineering process. The conflicting demands of easy access and maintaining a fairly high rate of meaningful robotic/user interactions presented a dilemma to the design teams. Compromises were made in both areas such that a single control menu was designed which allows the student to utilize the robot in any part of the robot's envelope by a minimal number of switch closures. The control screen display that was determined best able to meet the needs of the students currently utilizes an overall matrix format that graphically mirrors the columnar format of the Prentke-Romich switch device.

The students use the software by a two-step process: 1) the student must set up the desired motion by selecting one or more of the columns, and 2) the student then hits the "GO" button to execute the motion. The columns are accessed by scanning methods that require the student be able to depress the switches (individually or continuously, by holding the switch down). The five (5) columns have the following designated functions from left-to-right: Column 1: activates the "GO" option; Column 2: a direction selection column with "+" and "-" symbols; Column 3: cartesian axis selection column with "X", "Y", "Z" and "R" symbols; Column 4: robot arm-joint selection function with letters "A" - "F" indicating each joint ranging from the gripper ("A") to the "waist" motor ("F"); Column 5: pre-programmed position selection function, includes six (6) available positions each indicated by a colored rectangle.

Software Issue #2: Learner Control Features

1) **Understandable**: involves the ability of the user to understand the meaning and arrangements of the screen features. This includes a variety and range of considerations of both macro-level decisions (e.g. whether to use columnar or row layouts of information) to the micro-level decisions (e.g. the size of the individual alphabetical or numerical characters).
2) **Powerful**: means that features must have individual and collective functions that all work together to provide the most effective use of the robotic tool. Since the size and complexity of the screen display is severely limited, each character must not only have a single, critical function, they must also be able to work in combination with other characters in order to provide extended capabilities in the work environment.
3) **Complete**: the software must include all of the critical functions needed by the child and must incorporate as many of the capabilities of the computer in the design, including: data recording and management, communication displays, visual feedback, and the potential for interfacing other instruments. An example of this in the OSU software package is a "teacher utility" feature that allows for the therapist/user to adjust the input and certain system responses according to the needs of the student and the nature of the tasks at hand. Basically, it allows for immediate adjustments by either teacher or user of the input speed and interval delay responses while the robot is operating.

Software Issue #3: Defining Robotic Motions and Movement

The issues facing the definition of robotic motion were first approached by the determination of the space requirements of the student's educational tasks and of the available space within the robot's envelope. It was determined that the spaces behind the robot and on the periphery of it's operational envelope would eventually be used as tool storage places, while the primary working areas would be kept clear to allow for easy set up and use by teachers, therapists and students. Once the workspace's designated uses were determined it was possible to investigate the types of motions that students would need to appropriately access and use the robot. Four robotic movements were determined to be critically related to control over an educational environment. They specify movements in the following ways: 1) along a **cartesian coordinate system** that includes movements along the major axes of the coordinate system (X,Y, and Z), the resulting motion can be grossly described as up, down, left, right, in and out; 2) along a **cylindrical coordinate system** (as per UMI design conventions) that included the three coordinates of height, angle, and distance from origin; 3) with the **individual motors** at each of the axis points (degrees of freedom = 6) that involved simple movement of the joints (axis) of the robot in either available direction; and 4) to **pre-programmed positions** within the robot's envelope that the student could move directly to without going through any component movements.

FUTURE ISSUES

The current prototype system utilizing the UMI-RTX robot, IBM-PC AT computer, and the Prentke-Romich 5-slot switch is fully operational and is being tested in the field for a four-month period from February to May, 1989. The results of these tests are not available at the time of this report, but will be prepared and reported at the upcoming RESNA conference. The future is hopeful with many new ideas and possibilities for development of different software features and hardware components using new integrated graphics tools and a variety of adaptive input devices. We are also actively investigating the possibility of incorporating communication screens, scientific tools, workspace mapping utilities and other features of the robotic environment that continue to refine the capabilities and further empower the users.

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DEVELOPING SPECIFICATIONS OF A ROBOT FOR HEALTH CARE USE; STEP 1: DATA COLLECTION

14.5

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ABSTRACT

Developing robotic applications for the health care field is a long and complex process. This paper describes some of the issues associated with these developments as well as our approach for developing a robotic device for use in a long-term care institution for the elderly. Results of assessments of the environment, clients and care givers at one institution are reviewed with an analysis of their impact on the robotic application.

INTRODUCTION

A number of issues and constraints must be considered when applying a new technology such as robotics to the health care field [1]. The application must first of all be appropriate. There must be a real need served by the application. The people whom the technology will serve must not be alienated by the technology. They must have at least enough knowledge of the technology to allow them to eventually use the device. Furthermore, the way the technology interacts with the social fabric of its environment is also a concern [2]. A new technology, even one which appears to be well suited for a particular application, may not be utilized due to its appearance, staff conflicts, habits, and organizational influences (unions and other groups).

In the case of robotics as applied to health care, matters are complicated even further because of stereotypes attached to robots. The term robot conjures up images of an automaton which can only perform very limited tasks in a rote-like fashion, with limited regard to changes in the environment (as in an industrial setting)... a machine which can cause extensive damage to personnel or property if precautions are not taken. For people working in the health care field this description is a frightening prospect. This emphasizes the importance of safety [3] in the development of a robotic device especially for the health care field. In fact the application must not only operate safely, but it must appear safe.

The complicated technology of autonomous vehicles often requires many years of effort to produce tangible results. In the health care environment, the development time is lengthened considerably due to the time it takes to evaluate the technology by testing the working prototypes.

Due to the diversity of issues cited above and the time required to develop autonomous vehicle technology, our work has been divided into two key areas:

1. Research and development of generic autonomous vehicle technologies [4]; and
2. Identification of practical health care applications.

This paper presents a strategy for identifying practical health care applications. The approach here is to develop and model a specification for a potential robotic application for a particular health care area: an institution for the elderly.

METHOD

Our overall goal is the development of a patient assistive device that will use autonomous vehicle technology. In developing the specifications for a health care application, we have taken the following steps:

1. Assembling an assessment group of patients, staff and engineers who will develop the specification.
2. Measuring the environment and observing the needs of the clients.
3. Upon assessment of the environmental and client data and in collaboration with the assessment group, developing the specification for a robotic device.
4. Testing and refining the specification. Through an iterative process of developing models of the application and testing user reaction to these models and their specified capabilities, the concept will be refined.

The methods for data collection involved three approaches: (1) assessment group discussions; (2) environmental measurements; and (3) observation of daily regimes and residents' daily activities.

The aim of the assessment group was to identify possible robotic applications. The assessment group consisted of between 6-11 staff (occupational therapists, physiotherapists, nurses, recreologists, housekeepers, human resource and administrative staff) and one resident. The group was provided with a brief training session wherein the history and present day use of robots in industry and health care were described. Over the course of several meetings, a number of possible health care robotic applications were discussed. In these discussions, the main goal was to identify the overall characteristics of the robotic device as dictated by the needs of the client and the environment. Factors considered included the following: hazards and safety considerations; user identity and task characterization; robot physical description; operating environment description; user-machine interface and user training requirements; impact of a potential robotic application on the workload, work flow and social environment; and maintenance of the device.

RESULTS

In order to develop a special robotic vehicle for any environment, some idea is needed of the physical requirements for the vehicle, i.e. the maximum size and speed of the device. As well, with every different environment there is associated a variety of hazards a robot must identify. Environmental measurements and observations give insight as to the dimensions and overall characteristics of the autonomous vehicle application as well as its overall sensor requirements.

A variety of environmental measurements were taken. These included: light levels, sound levels, temperature variations, furniture measurements and characteristics, as well as physical dimensions of the environment. All of these measurements are important factors in determining the size, speed, type of lighting, and sensors the vehicle must have in order to deal effectively with the surroundings. Dimensions of rooms, hallways, doorways and potential obstacles were measured. The chart in Figure 1 provides a summary of the ranges of measurements taken at the Elisabeth Bruyere Health Centre. Using a "worst case scenario", the maximum dimensions for a robotic application can be surmised. The speed of electric wheelchairs at the Centre ranged from 4.8-9.6 km./hr., while residents with walkers move at a minimum of only 0.22 km./hr. The rooms themselves range in size from 13.5 to 46 sq. m. In each room the maximum amount of free floor space ranges from 10 sq. m. for the small rooms to 36 sq. m. for the large rooms. The number of clients in a room range from one to four.

Doorways (halls)	183 cm.
Doorways (rooms)	81 cm. - 111 cm.
Obstacles (halls)	31 cm. - 82 cm.
Hallways	244 cm.
Elevators	148 cm. - 163 cm.

Figure 1. Some of the measurements taken within the centre to help determine the maximum size of the robotic application. These measurements are needed for determining the maximum size of a vehicle operating in the environment.

DISCUSSION

Observations and discussions with the working group revealed that a robotic vehicle should operate no faster than the fastest vehicle presently in the environment. In fact a number of patients were observed to be alarmed by noise and quickly moving objects; 67 to 80 % of the residents are incapable of making a decision with respect to where they want to go (even while sitting in their wheelchairs); 80 - 95% of the residents require transfer assistance; the majority of residents are wheelchair dependent; and residents have major deficits in auditory and visual capabilities. These facts indicate that for most patients or while it is in hallways, a robotic device must operate at a slower speed.

A robotic device for carrying clients must be no narrower than 57 cm. (the width of a manual wheelchair). Theoretically the maximum width of the device must be less than 79 cm. in order to ensure that the vehicle will fit all passageways, allowing in the worst case for the Centre, a 1 cm. clearance on either side of the vehicle. In reality, the minimum range of the sensors and the navigation system will restrict the width of the vehicle even further. For instance some ultrasonic sensors for obstacle avoidance have a minimum sensing distance of 10 cm., reducing the vehicle width to less than 59 cm.

In the course of data collection, a number of hazardous situations were noted at the Centre. The most noteworthy being liquid spills and fallen or confused residents. A robotic application must accurately sense these hazards.

CONCLUSIONS

The importance of the assessment group's contribution cannot be overlooked, particularly because group discussions brought to the forefront issues and information which could not be gathered through patient record analysis or environmental measurements alone. As well, since this development will occur over a number of years and will touch the lives of everyone in the institution, it is important to have the involvement of representatives of the groups affected during the design process.

Phase 2 of this work involves the investigation of one of the applications that are currently under investigation by the group. A selected application will be modelled, its operation simulated and videotaped and then tested by assessing the reactions of the group and patients to the device in its simulated operation. It is expected that through this technique, a variety of specifications of the robot can be tested quickly. As well, it is expected that specifications for environmental and hazard-specific sensors and actuators required by the robotic device will be developed.

ACKNOWLEDGEMENTS

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DESIGN OF A HUMAN-MACHINE INTERFACE OF A VOICE CONTROLLED VOCATIONAL ROBOTIC WORK STATION

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I. INTRODUCTION

The utility of a voice controlled robotic work station for people with quadriplegia is dependent on many factors, one of which is a system that functions under the command of the user so that it is amenable to the user's changing needs. This paper discusses a design of a human-machine interface intended to enable technically non-trained individuals to customize and command a voice controlled robotic work station.

II. DESIGN CONSIDERATIONS

The functional requirements that robotic work stations must meet have been well established [1,2,5]. A work station has been designed for an office setting that (1) incorporates a large vocabulary speech recognizer eliminating the need for typing, (2) provides the ability to acquire and manipulate standard objects found in the office and (3) employs an intuitive user interface that allows the user independent customization of the speech recognition vocabulary and the robotic motions, minimizing the need for technical support.

III. HARDWARE

Commercially available off-the-shelf hardware has been combined to implement the work station. The system includes a Universal Machine Intelligence (UMI) RTX. It is controlled by a Kurzweil Voice System (KVS) 1000 word recognizer that emulates the computer keyboard. In addition to the KVS, a Kurzweil Voice Writer (KVW) 5000 word recognizer is employed to transcribe office correspondence dictated by the user.

IV. THE ROBOT MOTION EDITOR

Most reliable speech recognizers are discrete word recognizers with limited vocabularies. This forces the user to memorize the vocabulary. To assist users in this task, vocabularies are designed to be "mnemonic" so that words and phrases make sense for a given action in a particular context. A good example is the large vocabulary and set of translations that form VoiceRAD, a radiology reporting system [7]. We have designed an interface to the robotic work station based on the same principles that guided the vocabulary development of VoiceRAD. The interface is called the "Robot Motion Editor" and has been designed with the goal of putting the user in control of the vocabulary development and robot motion instruction process.

By operating the Robot Motion Editor, the user can "teach" the robot how to retrieve and manipulate a cup. The user employs the Robot Motion Editor to: (1) add the phrase "GET MY DRINK" as a mnemonic to refer to object retrieval, (2) train the translation of the phrase as a robotic motion by using a pre-trained vocabulary that serves as motion primitives (e.g. "right", "left", "up", "down", etc.) to move the robot's gripper to a desired location, and (3) train the location of the object by saying "LEARN WHERE IT IS". The Editor also allows the user to teach the robot how to avoid obstacles in its path by specifying intermediate points in the gripper's trajectory.

Teaching the motions or gesture to the robot can be a time consuming process. To improve the robot's responsiveness to the user, an automated grasping and sensory feedback component has been incorporated into the system design that is invoked when the user says "LEARN WHERE IT IS." The time it takes the user to teach the gesture is reduced since fine scale manipulation is much more time consuming than large scale manipulation. The sensory feedback and automated grasping algorithm employed is described elsewhere [3].

Figure 1 illustrates the top level menu of the Robot Motion Editor. The top two lines of the editor describe the state of the system. Beneath the status lines are two lists of words and phrases. The Editor organizes the speech recognition vocabulary according to the objects the user defined. On the left is a list of "OBJECTS". The list is a set of phrases the user has defined which correspond to the objects in the robot's workspace. The top two entries of the "OBJECTS" list are "Add an object" and "Delete an object." These entries provide the user with a method of teaching the robot about new objects or deleting objects that will no longer be used. On the right side is a list of "MOTIONS" corresponding to the current object highlighted. The user can select an object by either speaking the name of the object or by moving the highlight to the word (e.g. by saying "cursor down"). As the highlight moves down the "OBJECTS" list, the "MOTIONS" list on the right is updated with the phrases that are relevant for manipulating that object. For example, the object highlighted in Figure 1 is "DRINK". On the right is a list of phrases that correspond to how the robot has been trained to manipulate that object (e.g. "TILT MY DRINK").

When the user selects the object "DRINK", the screen is updated (Figure 2). The status line indicates the current object that has been selected and the current motion highlighted. The "MOTION" list appears on the left. The top three entries provide the user with a method for modifying the vocabulary and motions that allow for object manipulation: "Teach a motion", "Delete a motion", and "Re-teach a motion". When the user says "Teach a motion", a new motion not currently in the list can be specified. The user enters the mnemonic for the motion by either speaking or spelling the words. Once the new phrase has been specified, the screen is updated as shown in Figure 3. A window entitled "Teach the Motion" provides visual feedback for users. At this point, the system waits for the user to specify a motion. By using a set of motion primitives, the user can control the motion of the robot. For each motion primitive the user speaks (e.g. "RIGHT"), the translation is echoed on the screen and the robotic manipulator moves accordingly. In the case of mis-recognition, the user stops the robot and speaks the intended motion primitive again. When the robot is in the general vicinity of the object desired, the user says "LEARN WHERE IT IS". An automated grasp is invoked and when the object is located, the system responds to the user by prompting "What do you want to call this location?" The user can respond by saying or spelling the location.

When the process of teaching a motion is complete, the KVS goes into an automatic training mode that allows the user to record voice samples of the new robot motion phrase that has been added to the KVS.

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When the training is complete, the Editor returns to the top level menu (Figure 1).

By saying "Delete a motion" the "MOTIONS" list is updated so that the top three entries disappear and only the motions remain. When the user says one of the motions, the Editor prompts the user for a confirmation and deletes the motion if confirmed. "Re-teach a motion" updates the "MOTIONS" list in a similar fashion and allows the user to define the motion in a similar fashion to "Add a motion".

The user can also use the robot motion editor to execute a motion. In this way, the Robot Motion Editor functions as a help utility. For example, if the user wants to retrieve the drink from the table, at the top level menu (Figure 1) he/she says "DRINK". The screen is updated (Figure 2) and the user can say "GET MY DRINK" at which point the robot executes the motion.

An important feature of the Editor, when used as a vocabulary helper and control interface to the robotic manipulator is that, at all times, the active vocabulary appears on the left of the screen and the result of its execution appears on the right. For example, in Figure 2, the active vocabulary consists of motions to manipulate an object. The result of speaking any of the phrases corresponds to moving the robot's gripper to the designated location. When the execution of the motion is completed, the Editor returns to the top level menu (Figure 1).

An additional feature that the Editor accommodates allows the user to construct motions out of pretaught motions. For example, the user might create a phrase "PUT THE DRINK NEAR MY MOUTH" out of "GET MY DRINK" and "TILT THE DRINK". This is similar to the principal upon which LOGO is based. "New commands once defined can be used to define others" [6].

V. FUTURE WORK

The need for user verification of recognized speech will be examined. Mis-recognition handling needs to be incorporated into the system, possibly with a backtracking mechanism as described by Lees *et al.* [4].

The utility of the system will be evaluated by monitoring user performance and productivity. The system will be initially tested at the hospital while users are trained in its operation. Modifications will be made as needed. An alpha release of the system will be made initially to one office setting along with a client placement.

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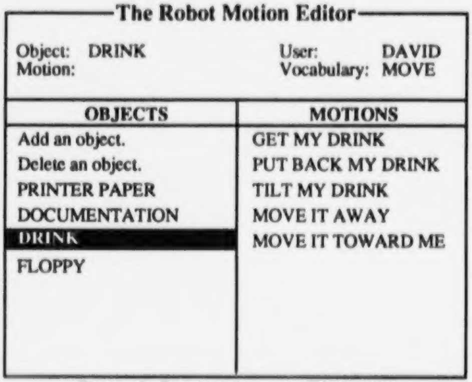


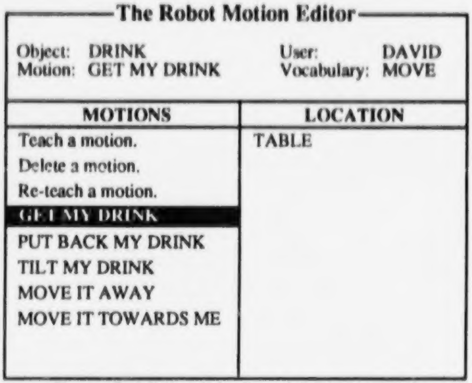
The Robot Motion Editor

Object: DRINK
Motion:

User: DAVID
Vocabulary: MOVE

OBJECTS	MOTIONS
Add an object.	GET MY DRINK
Delete an object.	PUT BACK MY DRINK
PRINTER PAPER	TILT MY DRINK
DOCUMENTATION	MOVE IT AWAY
DRINK	MOVE IT TOWARD ME
FLOPPY	

Figure 1: *Top level menu: Object list*



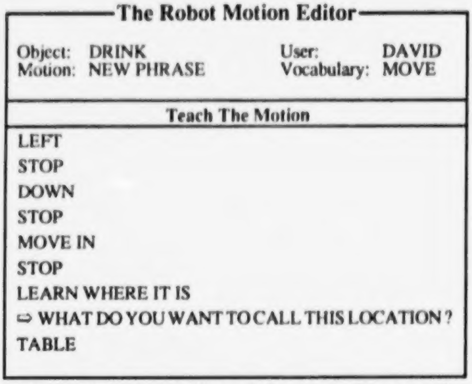
The Robot Motion Editor

Object: DRINK
Motion: GET MY DRINK

User: DAVID
Vocabulary: MOVE

MOTIONS	LOCATION
Teach a motion.	TABLE
Delete a motion.	
Re-teach a motion.	
GET MY DRINK	
PUT BACK MY DRINK	
TILT MY DRINK	
MOVE IT AWAY	
MOVE IT TOWARDS ME	

Figure 2: *Motion list after object selected*



The Robot Motion Editor

Object: DRINK
Motion: NEW PHRASE

User: DAVID
Vocabulary: MOVE

Teach The Motion

LEFT
STOP
DOWN
STOP
MOVE IN
STOP
LEARN WHERE IT IS
⇨ WHAT DO YOU WANT TO CALL THIS LOCATION ?
TABLE

Figure 3: *Teaching the robot a new phrase and corresponding motion.*

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ISOKINETIC STRENGTH TESTING: FULL BODY LIFTS VS SEGMENTED LIFTS

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ABSTRACT

The success of any screening or work capacity program requires accurate information on actual job demands as well as precise measurements of worker capacities related to key job demands. A device has previously been described that can measure a person's whole body strength. The present study demonstrates the feasibility of using a single floor to overhead lift to represent a person's strength throughout his range of motion in the sagittal plane. Few significant differences were found when performing lifts in segments.

INTRODUCTION

A previous study (Weisman, 1987) described a device that can measure a person's vertical lifting strength isokinetically. The study showed the device to produce repeatable results. The output of the device provides a description of the person's strength throughout his range of motion in the sagittal plane.

The method used to test the subjects' strength in the previous study involved having the subject lift from the floor to a position overhead in one motion. Lifts were performed at each of four horizontal distances from the body. While the output showed the person's strength throughout his range of motion the issue was raised as to whether or not the location of the start of the lift affected the value of strength obtained.

The purpose of the present study was to determine if a single full lift provided the same information as a series of segmented lifts representing the same range of motion.

METHOD

Subjects. The test group consisted of ten male volunteers between the ages of 22 and 38. No subject had any history low back injury, pathology or surgery and all were recruited for participation based on these criteria. Table I lists the anthropometric variable for the subject population.

TABLE 1. Subject Information

	Mean ±S.D.
AGE (years)	24.7 +/- 5.9
HEIGHT (in.)	69.5 +/- 2.3
WEIGHT (lbs)	163.6 +/-18.5
ARM LENGTH (in.)	25.5 +/- 2.0
WAIST HEIGHT (in.)	36.5 +/- 1.7
SHOULDER HEIGHT (in.)	58.2 +/- 2.6

Procedure. Each test session consisted of: (1) Three full vertical lifts (Seg 0) in the midsagittal plane from floor to head height, (2) three lifts at each of three body segmented regions: floor to waist (Seg 1), waist to shoulders (Seg 2), and shoulders to head (Seg 3). Both segmented and full lifts were performed at 4 horizontal distances (HD) at a test speed of 12 in/sec. The horizontal distances were determined as a percentage of arm length and included distances of 30% (HD1), 50% (HD2), 70% (HD3) and 90% (HD4).

RESULTS

Statistical analyses of the data were made using a within-subjects, completely crossed ANOVA program. The dependent variable was the force value at each of 35 heights. The four HD and each segmented lift were analyzed separately. This repeated measures model tested for differences between full and segmented body lifts, repetitions, and height for each individual subject. A summary of the ANOVA results are presented in Table 2.

Height. Six of the twelve probability values for height were highly significant. Force values at each height during the full lift (Seg 0) at all horizontal distances was found to be significantly different ($p<0.05$). Seg 2 was not significant at 3 of the 4 HD. Seg 3 was not significant at one of the 4 HD and Seg 1 was not significant at 2 of the HD.

Segments. Two of the twelve probability values were significant for differences in force generated during full lifts as compared to Seg 2 lifts at HD 1 & 4. Cell mean values were averaged over repetitions and height calculating an average force value at HD 1 for the full lift of 85.1 lbs and for Seg 2 of 91.9 lbs. At HD 4 the values were 38.1 lbs and 41.7 lbs for Seg 0 and Seg 2 respectively.

Segment X Height. This interaction was found to be significant at HD 1 with a full lift and Seg 1. Cell mean values were averaged over repetitions to evaluate the interaction. Seg 1 was found to have an average force value of 11.8 lbs greater than Seg 0 at each of the 15 heights analyzed.

Repetitions: These were found to be significantly different at HD 1 involving Seg 0 & 1. Cell mean values were averaged over height and segment. Repetition 1 = 148 lbs; Repetition 2 = 159.4 lbs; Repetition 3 = 163.1 lbs.

Segment X Height X Repetition. This interaction was found to be significant in three of the twelve measurements. Two involving HD 3 and one involving HD 1.

Although not specifically analyzed it was observed that the force values decreased as one moved out horizontally away from the body, i.e. HD 1 > HD 2 > HD 3 HD 4.

DISCUSSION

The results of the height analysis confirmed the results of the previous study. The insignificance of Seg 2 may be explained in a number of ways. Seg 2 contained the few- est force values. Seg 2 required wrist manipulations which may create some variab- ility in a small compact area represented by only a few force values.

The primary purpose of this study was to demonstrate that segmented lifts are equivalent to full body lifts. The fact that only two of the twelve probability values were significant makes a very good case for this hypothesis. As described above Seg 2 had the fewest number of force values. It should be noted that HD 1 and 4 were tested first during each day's testing. The significance may be the result of warm-up or familiarity with the machine. In any case, the force values, when calculated from the raw data, were no more than 7 lbs. different between segments.

The significant differences at HD 1 involving Seg 0 & 1 may be attributed to a warming up phenomenon as seen by the progressive increase in force values from Repetition 1 to 3.

The interaction between segment, height and repetition is very difficult to interpret. It suggests that with one of the seg-ments, during one of the repetitions, the height becomes sig-nificantly different than it's counterpart. Due to the complexity of the interaction its usefulness in this study is limited.

CONCLUSIONS

This study has confirmed previous results demonstrating the repeatability of an isokinetic strength testing machine. The results demonstrate the utility of performing a single floor to overhead lift to determine the lifting strength of an individual in the sagittal plane. The values of strength are independent of where the lift originates.

ACKNOWLEDGEMENTS

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TABLE 2: ANOVA Probability Values

	S	H	SH	R	SR	HR	SHR
HD1: S0,1:	0.0902	0.0000*	0.0004*	0.0083*	0.4113	0.1311	0.5839
HD1: S0,2:	0.0078*	0.1808	0.9290	0.8963	0.8545	0.9660	0.0025*
HD1: S0,3:	0.6653	0.0000*	0.9900	0.6995	0.6599	0.4934	0.9566
HD2: S0,1:	0.4623	0.0012*	0.6423	0.7969	0.4312	0.6792	0.9241
HD2: S0,2:	0.2132	0.8361	0.4689	0.9367	0.6542	0.7075	0.4201
HD2: S0,3:	0.3426	0.0001*	0.5401	0.6335	0.5182	0.5985	0.6675
HD3: S0,1:	0.6510	0.4766	0.7995	0.9704	0.4720	0.3180	0.0046*
HD3: S0,2:	0.2612	0.9809	0.5260	0.9344	0.3605	0.2759	0.0147*
HD3: S0,3:	0.0878	0.6681	0.7217	0.5240	0.0853	0.4299	0.8076
HD4: S0,1:	0.9942	0.7725	0.5466	0.7294	0.5138	0.5117	0.6733
HD4: S0,2:	0.0458*	0.0002*	0.9139	0.8298	0.3283	0.9024	0.7138
HD4: S0,3:	0.2258	0.0001*	0.8215	0.2821	0.6871	0.5956	0.4771

HD=Horizontal Distance S=Segment H=Height
R=Repetition * p<.05

15.2

IMPROVEMENTS IN THE DESIGN OF A 3-AXIS ELECTROGONIOMETER FOR THE RECORDING OF TRUNK MOTION IN THE WORKSITE

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ABSTRACT

The posture workers assume while performing work tasks may contribute significantly to the onset of low back pain. Workers are especially at risk when required postures exceed their normal trunk range of motion. A system for measuring three-dimensional trunk motion in the workplace has been described in a previous study (Beynnon, 1986). Improvements in analysis techniques have been made and are presented in the present study. Results are presented for postures assumed by five men working as sheetrockers.

INTRODUCTION

The development of chronic low back pain (LBP) is often gradual and insidious and may result from the cumulative effects of repetitive loading of the spine. The effects of spinal loading, e.g., during lifting, also vary with postural configurations (Pauly, 1966). The association between awkward work postures and the development of musculoskeletal disorders including LBP, has been widely documented (Corlett & Bishop, 1976; Magora, 1972; Tichauer, 1978; Van Wely, 1970). Colombini et al. (1985) describe tolerable working postures as (a) those which do not involve feelings of short-term discomfort and (b) those which do not cause long-term morpho-functional complaints.

A previous study (Beynnon, et al., 1986) described an electrogoniometer that continuously measures trunk range of motion in the worksite environment. The device is harnessed to a worker who remains unconstrained while performing tasks. The harnessing consists of two plates that attach posteriorly to the sacrum and mid-scapular region via adjustable velcro straps. Attached to the sacral plate are three electrical potentiometers that align with the physiologic axes of flexion/extension, lateral bending and axial rotation. The accuracy of the device and repeatability of measurements were demonstrated in the previous study by comparing the output of the goniometer to a photographic method and a plastic clinical goniometer. A linear correlation of the electrogoniometer to the other two techniques yielded r^2 values of at least .95 for all rotational axes of motion.

The device described previously allowed for the spatial analysis of working postures. Data were "binned" to represent the total time spent in a particular posture. This method provided a single value of time for each posture. A typical plot is shown in Figure 1. A problem was soon noted with the presentation of data in this way. If a specific "bin" represented a value of time of 10 minutes, it could not be determined if the value represented a single posture maintained for 10 minutes or 10 postures maintained for 1 minute each.

METHODS

The device is described fully in the previous study. However further development has resulted in a comprehensive software package that analyzes the trunk motion spatially as well as temporally.

Description of Analysis Software: At the present time data are collected from the goniometer by an FM tape recorder. The tape recorder is capable of recording up to three hours of data. The tape is played back through an A/D board into a PC. The program tabulates the data by counting the amount of time that a specific posture is held. When another posture is assumed the next entry in the table is written. This continues until all data is tabulated. The table represents all postures assumed in chronologi-cal order with a value of time for each posture.

The tabulated data are then used to create a "rubic's cube" of postures. Each posture is represented by a spatial "bin" with a resolution of not less than 5 degrees within the cube. Each spatial bin can contain up to nine time bins representing the length of time a specific posture was maintained thus providing an indication of the 'quality' of time spent in various postures. The software allows the analyst to "collapse" any of the three dimensions in order to plot the results. The time bins are represented by stacked bars within a spatial bin. The time bins can also be collapsed.

Data Collection: Data were collected on five men putting up sheetrock at a local construction site. A typical plot is shown in Figure 2. Future data collection will be conducted with a portable computer instead of the FM recorder. The data will be tabulated in real time thus eliminating the need for the transition from tape through the A/D board to the PC.

CONCLUSIONS

An electrogoniometer has been designed and built that can be worn by a subject for continuous measurement of trunk motion as described previously. A computer program has been developed that can analyze the data both spatially and temporally. Data are presented graphically.

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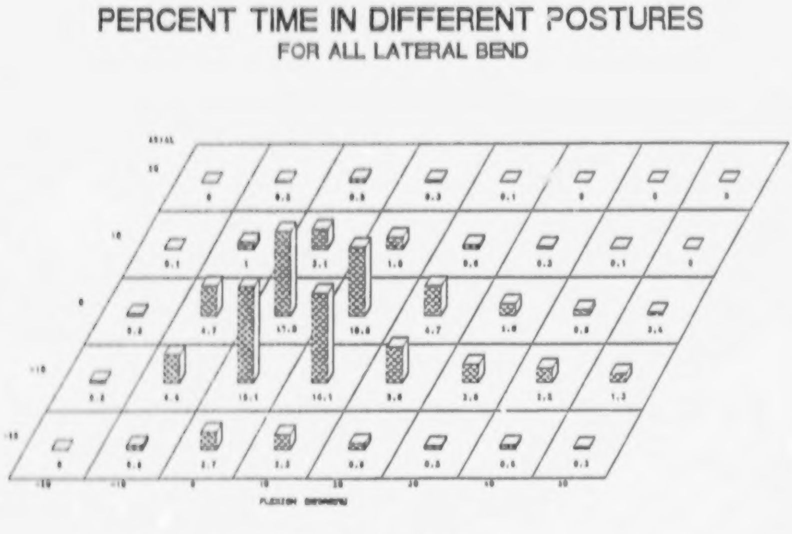
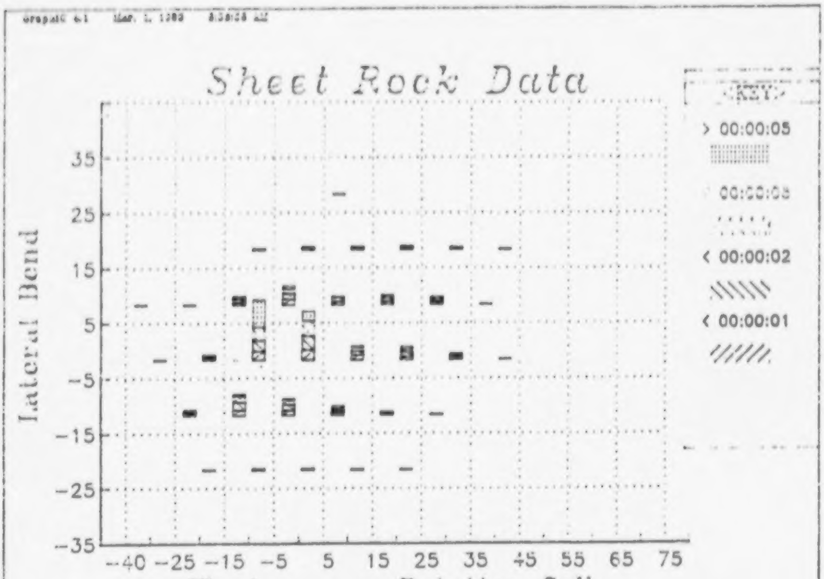


Figure 1. "Binned" Goniometer data



DESIGN OF A POSITIONING APPARATUS FOR THE CLINICAL STEREORADIOGRAPHY OF THE SCOLIOTIC SPINE AND RIB CAGE

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ABSTRACT

An apparatus was designed to normalize the position of scoliotic patients during stereoradiography in a clinical environment. The apparatus is ajustable for patients of any height and size and is composed of a calibration object which allows tridimensional (3-D) reconstruction of landmarks on the spine and on the ribs. A sliding X-ray cassettes replacement system easy to use by the X-ray technicians minimizes the time between the two exposures. The 3-D reconstruction accuracy obtained with the apparatus is less than 0.6 millimetres (mm.) on measurements of linear distances.

INTRODUCTION

In order to obtain the 3-D reconstruction of the spine and the rib cage of scoliotic deformity from stereoradiographs, the design of an apparatus normalizing the position of the patients was developed for the clinical evaluation of all idiopathic scoliosis patients at Sainte-Justine hospital. Different apparatus of this kind have been developed by other autors [1,2,3,4,5] but they have been used for specific research goals and not for a routinely use in a clinical environment. These apparatus were also limited to the reconstruction of the spinal structure only. This paper presents the different design criteria and the description of a new apparatus as well as a validation method used to evaluate the accuracy of the 3-D reconstruction obtained with it.

DESIGN CRITERIA

The positioning apparatus was designed to reach the following criteria:

- obtain the standard clinical posterior-anterior (P-A) view and a second view with the X-ray tube lift up to form a 20 degres angled down P-A view in order to obtain a stereo pair including both sides of the rib cage [6];
- maintain the patient in a stable position to minimize his movements between the two X-ray exposures;
- be independant of the hability of the X-ray technicians;
- minimize the time between the two exposures;
- be ajustable for patients of different heights;
- minimize patient's fear;
- occupy minimun space in the X-ray room.

DESCRIPTION OF THE APPARATUS

The positioning apparatus is presented in figure 1. The patient has to stand on foot prints drawn on the ajustable floor and is maintained rigidly in position by the positioning devices. The first clinical P-A view is then taken, followed, after sliding an unexposed X-ray cassette, by the second P-A view (20 degres tube up).

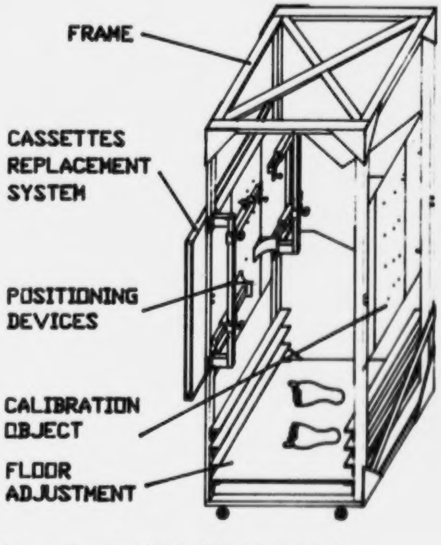

Figure 1 - Positioning apparatus

The positioning devices are designed in order to normalize the patient's position between different visits and to minimize the lateral and postero-anterior movements of the trunk between the two X-ray exposures. This is done by adjusting curved pads at the pelvis level and by positioning plastic balls just under the clavicles. The positioning devices allow height and lateral adjustements in order to fit patients of different ages and different sizes. If the range of height adjustment allowed by the positioning devices is not sufficient, it is possible to compensate by a floor adjustment. By sliding the floor on tracks welded on the frame of the apparatus at each 10 centimeters of elevation, it is possble to X-ray patients of heights varying between 1,00 and 1,85 meters.

The calibration object is built on the apparatus in order to allow 3-D reconstruction of any anatomical structure inside its limits. The calibration object is composed of two acrylic sheets positioned parallel to the X-ray film plane and on which 3-D coordinates of five rows and five columns of calibration points (small radiopaque steel balls of 2 mm of diameter) per sheet are known. These points symmetrically distributed on each sheet are visible on the stereoradiographs. The patient is X-rayed between these two sheets. Then, stereo images of these calibration points can be digitized and the DLT reconstruction algorithm [7] can be applied to obtain 3-D coordinates of anatomical landmarks on the spine and on the rib cage. A side acrylic sheet increase the rigidity of the calibration object. The acrylic material was chosen besause of its transparency to the X-rays and to the light in order to reduce the patient's claustrophobic sensation.

The fact that the calibration object is incorporated to the positioning apparatus do not require to always position the X-ray source exactly at the same location for different patients and different visits (as it is often the case in "classical" strereoradiography) because the DLT program calculates intrinsically the stereo positions of the source. Consequently, the 3-D reconstruction with this apparatus becomes independent of the hability of the X-ray technician to reposition the X-ray tube at their exact locations.

The sliding X-ray cassettes replacement system is designed to minimize the time between X-ray exposures. This system allows the loading of two cassettes (36" x 14"). Two lead shields placed on both sides of the apparatus allow the films to be exposed one at the time avoiding surexposition. Then, during the first X-ray shot, only one film is exposed. After, both cassettes have to be slided in order to expose only the second film. Finally, the cassettes have to be slided back to be removed from the apparatus.

VALIDATION METHOD

The 3-D reconstruction accuracy obtained with the apparatus was evaluated as follow. The 3-D coordinates of the calibration object was determined by X-raying another calibration objet of dimensions slightly smaller than the one on the apparatus and on which the 3-D coordinates were known with an accuracy of 0.1 mm. Three series of strereoradiographs were taken with slightly different positions of the smaller calibration object inside the apparatus. The 3-D coordinates of the calibration object mounted on the apparatus were determined by taking the mean values obtained from the extrapolated reconstruction procedure. Then, an object of known dimensions was reconstructed using these new calibrated coordinates. Five linear distances in X (horizontal), Y (vertical) and Z (deep) directions obtained after 3-D reconstruction were compared with the corresponding X, Y, Z distances measured directly on the object.

RESULTS

The mean absolute differences of these linear distances were 0.1 mm in the X direction, 0.2 mm in the Y direction and 0.3 mm in the Z direction. The maximun differences were respectively 0.2 mm, 0.4 mm and 0.6 mm.

CONCLUSION

The apparatus described in this paper is adequatly accurate for 3-D reconstruction. This new apparatus used in a clinical environment gives the opportunity to obtain routinely the 3-D spinal and rib cage geometries of all patients evaluated at the scoliosis clinic. With this new clinical tool it is now possible to have access to a large amount of geometrical data which can be used for clinical analysis as well as for fundamental research.

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EFFECTIVENESS OF CERVICAL SPINE STABILIZATION DEVICES

II: Accelerometric Identification of Risk Factors During Installation and Use

15.4

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ABSTRACT

Movement of the acute spinal cord injury (SCI) patient—whether over long distances via air or ground vehicles, or short distances, such as lifting from a bed—entails a risk of unintentional vertebral motion despite the best efforts to maintain spinal stability. We previously reported on the beginning of a pilot project to employ acceleration measurement and analysis to examine hitherto unmeasureable biomechanical inputs and body segment responses /1/. Herein we describe early results that pertain to validation of the method and identification of incidents during installation and simulated clinical use that produce higher-than-background motion of the head relative to the body. These include: closure of fasteners, contact of edges of backboards with the floor, and movement of the head within its restraints.

INTRODUCTION

In early treatment of a SCI patient, effort is made to restore and preserve vertebral alignment, both by immobilization using spineboards, collars, straps, sandbags and other forms of restraint /2/, and by traction applied by skeletal tongs attached to weights or constant-force springs /3/. Testing effectiveness by static radiography /4, 5/ does not provide quantitative data on the dynamic environment.

In our study we measure acceleration during procedures which the typical spinal injury patient undergoes, including:

- Placement and movement on a backboard with or without traction,
- Lifting with manual traction, as done to transfer the supine patient from a backboard to a bed, and
- Placement in traction on a kinetic bed followed by side-to-side tilting.

We tested several new devices including: the "TACIT" (Minto R&D, Redding, CA), a short spineboard with head supports capable of applying noninvasive traction, the Miller board (Life Support Products, Inc., Irvine, CA), the Dixie "2001" backboard (Dixie USA, Inc., Houston, TX), and a carbon fiber/epoxy composite backboard /3/ for inter-hospital air transport with tong traction.

To reduce skin, respiratory and vascular sequelae, the patient may be placed on a "kinetic" bed that is tilted about its longitudinal axis ("RotoRest", Kinetic Concepts, Inc., San Antonio, TX). McGuire /6/ and Salciccioli and Kuric /7/ made radiographic measurements of neck angulation during turning while in traction, showing neck angular motion of 2 to 9°.

In lifting a patient, it is difficult to objectively assess whether the head is stationary relative to the body. Studies of the "log-rolling" maneuver showed that unstable lumbar vertebrae were displaced up to 21 mm laterally and 30° in rotation when rolled to 45°; on a backboard or scoop stretcher transverse displacement was 4 to 7 mm and rotation 4 to 30° /8/.

Morris /9/ advocated accelerometry for gait analysis, using single-axis accelerometers mounted on a tibial cast. Accelerometers may be strapped to a living subject, cadaver or dummy /10/ or held in a bite bar /11/.

METHODS

Measurements are made using miniature (0.5 inch cube) 3-axis 5-g range accelerometers (Entran Devices, Inc. EGA3) strapped to the head and the chest (Figure 1). A cable tension transducer (Entran ELF-1000; 50 lb.) provides an indication of the traction force, if any.

Each 120-second run began with installation on a supine able-bodied volunteer, who was then log-rolled 60-90° to each side, raised 20-90°, and asked to exert muscular effort against the neck restraint in compression, in flexion/extension and laterally. Procedures are recorded on videotape synchronized with the acceleration record against a grid backdrop, so that absolute position can be derived from video images. Details are being published elsewhere /12/.

RESULTS

Whether motion measured at the skin corresponds to skeletal motion is a question applicable to virtually all non-radiographic methods. The difference between biteblock-mounted and forehead strap-mounted accelerometers during unrestrained angular motion is summarized in Figure 2. While most peaks are within a 0.02 g range, Y-axis differences are up to ±0.12 g, illustrating a tendency of the forehead strap and/or skin to slip relative to underlying bone.

The installation phase (14 to 25 sec duration) of the Miller head restraint is shown for two different subjects in Figure 3. Pulling chin and forehead straps to engage Velcro fasteners generates peaks of 0.17 to 0.34 g above background for typically 0.5 sec. Double integration over the 2.0 sec interval surrounding the peak marked by an arrow in Figure 3 yields a net displacement of -3.4 cm on the X axis.

The log-roll maneuver illustrates the ability to superimpose tests performed on different times and subjects (Figure 4). The Miller board consistently imposes a differential X-axis acceleration due to variation in the angles of the head and thorax relative to gravity; i.e.: the neck is flexed during rotation regardless of whether the roll is to the left or the right of vertical. Peaks which occur at similar times during the roll may be assumed to have similar causes, such as those occurring immediately before return to the supine position (arrows in Figure 4).

Improvement in restraint against lateral head motion is evident by comparison of log-roll maneuvers on the composite backboard with and without a contoured neck support. The maximum relative Z-axis angle for the right roll to 60° was reduced from 25° (0.43 g) to 13° (0.23 g). Traction was 5 lbs.

Testing of traction force on the RotoRest bed (Figure 5) confirmed published observations of variation with angular position [13]. Results showed a half-sinusoidal oscillation of 0.8 lb or 17% added to the minimum force, which was 0.2 to 0.4 lb less than the 5 lb weight on the traction cable due to frictional loss. Peaks of 6.2 to 6.5 lb (130% of nominal force) occurred at the extreme 60° angle of tilt.

CONCLUSIONS

It was not the intent of this pilot study to rank or otherwise criticize the devices which we tested, but rather to demonstrate how they might be evaluated unter dynamically realistic conditions of use. The use of a particular stabilization device as an example should not be construed to imply that it is either better or worse than comparable devices.

The accelerometric method is particularly appropriate for identifying specific times or activities during installation and use of a stabilization device which create higher-than-background accelerations, and therefore higher risk of unintentional neck displacement. Examples of such high-risk events which are common to several devices are:

- Closure of fasteners during installation,
- Contact of backboard edges with floor for log-rolling (Figure 5),
- Slipping of the subject's torso, or less frequently legs, if straps have not been adequately tightened,
- Jostling as the attendant's hands grasp the board,
- Progressive loosening of Velcro attaching the head restraint to the edge of the Miller board, and
- Dropping of the end of the board when the attendants' hands are released.

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Figure 1: Accelerometer, X,Y,& Z Axes

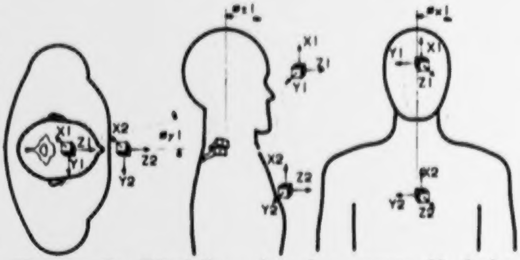


Figure 2: Biteblk - head mount: Y Axis

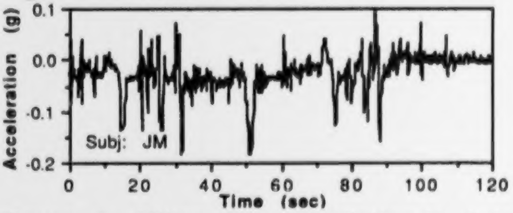


Figure 3: Miller Bd: Installation-X Axis

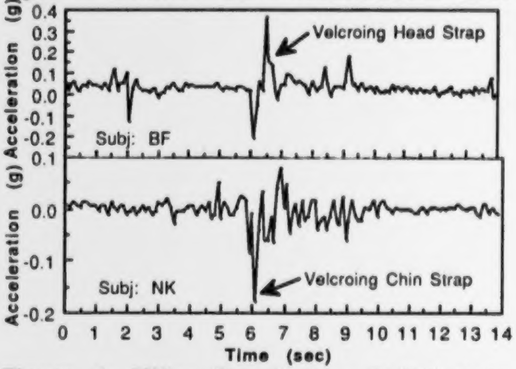


Figure 4: Miller Board: Log Roll-X Axis

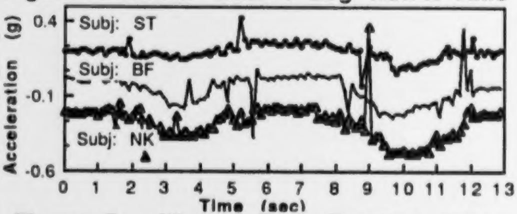
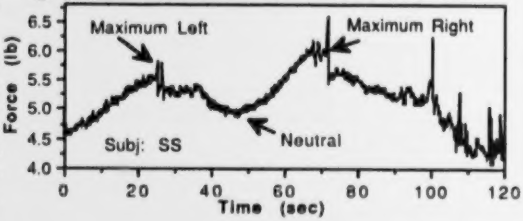


Figure 5: Kinetic Bed: Traction Force



THE DYNAMICS AND CONTROL OF SIDE TO SIDE SWAY IN THE FRONTAL PLANE

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This work describes our efforts to analytically and experimentally study the gross dynamics of human side to side sway. Our ultimate goal is to develop a gross mechanical model and investigate control strategies of the organization of human movements in postural stability and other maneuvers.

The analytical work has involved formulating a mathematical model of a four link biped in the frontal plane with two legs, a hip segment, and a torso. For this function the thigh and shank are a single rigid body with locked knees, and point contact is assumed with the ground under each foot. The parameters of mass, moment of inertia, length, and position of the center of mass for each of the four segments correspond to those of a human of average size. The totality of muscle forces operating at the five joints of the model are represented by five moments of force actuators, one at each joint. Passive viscoelastic elements are included in the actuator dynamics to represent natural muscle viscoelasticity. The model is situated with both feet on the ground with no slippage of the feet on the ground or lifting off the ground. The biped model is swayed from side to side. The four angles of the segments, and the two horizontal and vertical reaction forces under each foot are computed, and recorded as functions of time. The sway consists of keeping the hip horizontal and swaying the legs and/or the torso 6 to 8 degrees to one side from the neutral vertical stance. A number of different organizational control strategies are tested on this model. Four of these strategies are:

1. Only the hip and the torso actuators are active and ankle actuators are of a negligible influence.
2. Only the ankle and the torso actuators are active.
3. All five actuators are individually active with no coupling feedback between them.
4. All five actuators are dependently active and coupled by feedback such that the motions of the four individual segments are decoupled from one another.

To determine the efficiency of the model and which control strategy is utilized by humans an experimental study was performed. The experimental work involved recording of six different side to side related maneuvers by subjects at the Gait Analysis Laboratory of The Ohio State University. The movement of the four segments and the four reaction forces under both feet were measured for each of the six maneuvers using a VICON Motion System and AMTI force platforms. As an example of the data obtained the floor-ground reaction forces for maneuver 1 are shown in Fig. 1. The kinematic data obtained from the experiment was fed as the desired input to model and its response to various control strategies mentioned above was studied on digital computer. The floor-ground reaction forces obtained from the computer model was then compared to the data obtained for each maneuver as activity recorded from the force platform.

The computed floor reaction forces for three control strategies are shown in Fig 2. Since the angular trajectories and angular velocities are the same for all control strategies, the difference in the forces is primarily due to the muscular inputs at the joints. Based on the comparison of the measured and the computed forces it appears that the most agreement is found where each joint actuator has its own feedback mechanism and it is not cross-coupled through feedback with any other joint. This fact suggests the possibility of separate control centers in CNS for distinct body segments. Further work with the evaluate whether similar strategies are utilized in a variety of subjects with central neuromuscular deficits.

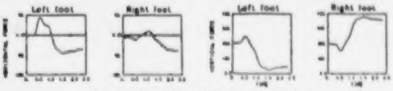
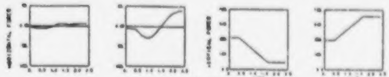
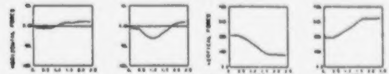


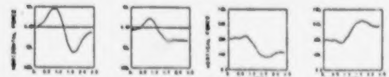
Figure 1. Ground Reaction forces under both feet.



a) ankle gains



b) decoupling gains



c) decentralized gains

Figure 2: Ground reaction forces computed from various control strategies.

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THE PEDABAROGRAPH SYSTEM : AN ASSESSMENT OF THE CURRENT TECHNOLOGY

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ABSTRACT: New technology allowing for the quantification and generation of computerized color graphics displays of foot pressure patterns is currently becoming available for use in both clinical and research settings. While these devices appear to be a useful tool for objective measurement of dynamic foot pressure patterns in a variety of disabled populations, the experience at our gait laboratory has demonstrated a number of difficulties with these devices. This study addresses limitations found in utilizing one such a device relating to the accuracy, efficiency, reproducibility and efficacy of the system applied to subjects with pathologies. It is hoped that this study will serve as a method of technology transfer by sharing our experiences and techniques and stimulating the flow of ideas and information to better utilize such systems as they become increasingly available.

INTRODUCTION: The patterns of pressure underneath the foot have long been of interest to clinicians and research scientists. Various devices have been developed and utilized over the years to measure these patterns including pressure mats, foot switch systems and force platforms. All of these devices have been shown to have limitations, both in the hardware's capabilities to specifically measure and in the software algorithms' ability to calculate and graphically display objective foot pressure pattern data. Currently, new technology has allowed for a number of PC-based, color foot pressure systems to begin to emerge on the rehabilitation technology market. Several commercially available devices appear to be useful tools for the objective quantification of foot pressure patterns in a variety of disabled populations.

METHODOLOGY: The complete pedabarograph utilized in the gait analysis laboratory of the Rehabilitation Engineering Center of The Ohio State University consists of the optical pedabarograph system as described by Betts et al(1), a NEC AP-IV computer, a Panasonic high resolution color monitor and a Polaroid AT high speed color plotter. The actual target area of the system is a 15 inch by 11 inch rectangle which is situated in a 15 meter walkway, along with force plates, used for gait analysis. The system has a spatial resolution of 256 by 128, which is sampled down to 128 by 128 or 2 mm. by 3 mm. The sampling rate is 30 images per second, with one sixtieth of a second for each image. The sampling interval is one second with no measurable time lag between the application of the pressure and the system response. The company-produced software allows for the output of monitor displays and color plots of specific pressure areas of interest analyzed by the user and generated as maximum and average pressure/time curves, integrated force curves, or color pressure outlines of the foot. This is quite useful for most applications.

RESULTS: Calibration of the device and reproducibility of the measurements are two pertinent topics. Calibration is usually supplied by the manufacturer and with these devices requires enormous pressure across the entire surface of the measurement area. Specialized hardware such as air bladders or pneumatic devices which are not readily available to most laboratories are needed for complete and accurate calibration. However, a protocol for benchmark testing of the system hardware was shown to be of use. The protocol used a variety of known weights, which were placed at various areas of the measurement surface with an applicator of known area and then incremented at intervals while data acquisition took place. Slight adjustments to the manufacturer supplied calibration data was then carried out, increasing the accuracy of the measuring device and demonstrating the linearity of the actual measuring surface of the device. The results of these techniques allowed us to demonstrate greater accuracy and good linearity across the measurement surface of the pedabarograph. It would appear that this process should be carried out on monthly basis to verify the accuracy of the hardware.

A second protocol involved subsequent testing utilizing a live subject who performed multiple walks and was also weighted in increments while foot pressure data was sampled. The results of these tests demonstrated that the pedabarograph appeared to be very linear across the measurement surface, had a sufficiently linear relationship between the applied and measured pressures, and that the instrument satisfied standards for repeatability/reliability in multiple measurements.

Another difficulty lies in the area of the software. In all of these systems a method by which the data is combined and processed in order to be useful to the clinician has not been fully developed. Nor has a protocol been agreed upon that addresses intra and inter subject repeatability. In order to provide the clinician with more useful and objective data a number of techniques have been developed. A standardized protocol for identifying specific pressure sites has been developed. The five distal metatarsal heads, two areas on the heel and the great toe are analyzed for each subject. A reference system which is easily located by identifying bony landmarks and thus provide a map of the plantar aspect of the foot is being developed to further facilitate comparison inter and intra subject repeatability. The technique involves placing small, flat rubber markers on the areas dictated by the identification protocol and then taking foot pressure data. This data can later be superimposed over the clinical data taken without the markers to provide a frame of reference in those clinical cases where the entire outline of the subject's foot may not have been recorded due to a pathological pressure pattern. The existing software allows the user to circle pressure site locations but does not calculate the actual surface area under the foot that this pressure is acting upon. Since high pressures distributed over smaller areas can present a greater clinical problem, software was written that calculates the centroid of the circled area, defines the radius of the circle and then calculates the actual area of the circle and scales this to the true size of the subject's foot surface.

Further, velocity factors and body weight could have affected the magnitudes of the pressures as is the case with ground reaction forces. Thus, to properly evaluate intra and inter subject repeatability, the magnitude of the pressures must be normalized based on the subject's weight and walking velocity. To determine these parameters a protocol was developed whereby three reflective markers can be placed on the foot while marker position data is recorded by the Vicon motion analysis system. Lab written software allows identification of the markers and calculation of the time-distance parameters (velocity, stride length, step length, cadence). Body weight and the actual ground reaction forces can be recorded and utilized as part of the overall analysis process. Maximum pressures for a given specified area could be "skewed" by relatively few pixels that displayed extreme pressure. These issues have been addressed by software that has been written at our site which counts the pixels in the circled pressure site and then generates a histogram giving us a count of the number of pixels representing each color (pressure) group. Statistical methods than determines which is the true representative group of the maximum pressures.

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NEW ILLUMINATION AIDS FOR LOW VISION

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ABSTRACT

Two new low vision lighting aids are described. The first is a general purpose head-mounted, battery-powered light for reading and other near tasks, designed to supply about 10 times normal room lighting intensity and cover most of a page at a normal reading distance of 16 inches. The second device is a spectacle-mounted lighting system specifically designed for those who must read at very close distances with a high-powered spectacle lens, and who normally have problems with ambient light being excluded by the shadow of the head.

PROBLEM STATEMENT

Achieving good illumination of reading matter or other near work is a vital factor in ameliorating the effects of many low vision conditions--especially the most commonly occurring (macular disease). In the latter case, a mild scotoma, which is commonly visualized as an obscuring hole in the retina, can in fact often be made functionally useful if the level of illumination is adequate. Unfortunately many presently available lighting systems suffer from drawbacks ranging from inadequate light output to excessive heat generation and inability to direct the light to where it is really needed. Accordingly, we have developed two prototype low vision lighting systems designed to address these needs.

BATTERY-POWERED, MULTIPURPOSE LIGHTING SYSTEM

We have designed, built, and tested a head-mounted, battery-powered, low-voltage, high-intensity supplementary lighting system (Figure 1) for use in reading and other near tasks--suitable for both low vision and more general (e.g., surgical) applications. The beam size is calculated to illuminate a page-sized area at normal reading distances.

The new prototype incorporates the quartz-halogen MR16 technology, and employs a precision reflector with dichroic coatings to alleviate the infrared problem common with conventional incandescent sources. The compact, lightweight, and efficient system is suitable for mounting on a head frame or band, spectacle, loupe, or hand magnifier to provide high-intensity localized illuminance, while the precision optics give excellent beam control and uniform illumination without "hot-spots," therefore minimizing glare to others.

The prototype uses a 20-watt bulb and a 5-lb., 12-volt, 5 amp-hour Ni-Cad rechargeable battery pack worn on the shoulder or belt, giving 3 hours of use at full intensity (half-power switching is incorporated).

Our laboratory tests on the prototype included a comparison test with a high-intensity, spectacle-mounted light used in ophthalmology. The light output of our system exceeded that of the comparison device by a factor of 20, providing two-and-one-half times the intensity and eight times the beam coverage, while using only twice the power. The resulting luminance of typical reading material was measured at 1000 candelas per meter squared for normal reading distances - representing approximately 10 times that resulting from normal ambient room lighting.

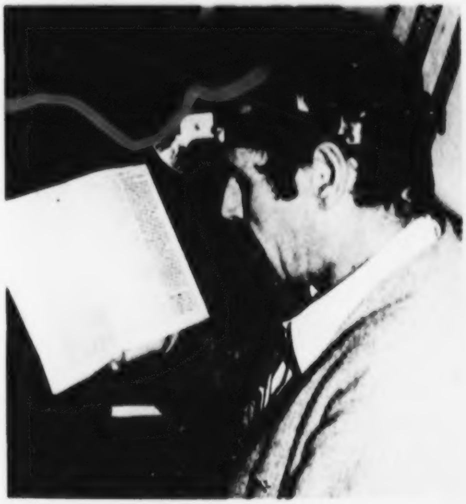

Figure 1. Battery-Powered, Multipurpose Lighting System

In tests and demonstrations of the unit to date (including its application in surgery using an optional add-on glass filter/protector in front of the bulb to filter out ultraviolet rays and for added shatter protection), all evaluators have been impressed with the intensity and quality of the resulting light, as well as the convenience of the head-mounted unit.

We are now exploring a number of improvements including the incorporation of just-available MR-11 technology, a more cosmetic headband, and a smaller battery.

SPECTACLE CLIP ILLUMINATOR

Many low vision patients read using high-powered (+20 to +40 diopter) spectacle lenses - resulting in a reading distance of approximately 1 to 2 inches. The problem faced by this population is that when the reading material is held up to the eye, the head partially or largely blocks any ambient illumination, making reading difficult. Our solution to this problem uses a small 1- to 2-watt light bulb and reflector which clip onto the user's spectacles so that illumination is projected on objects held within a few inches of the spectacle lens.

Our calculations, applying the inverse square law, indicated that a 1-watt light source used at a 2-inch working distance would cast approximately the same light intensity on the reading material as a 60-watt reading light used at a standard working distance of 16 inches. We have constructed several prototypes using bulbs in the range of 1 to 2 watts, with reflectors and spectacle clips of various designs. In each case, operating power is derived from a small alkaline or lithium battery cell carried in the user's pocket or purse. When not in use, the illuminator can be easily unclipped and pocketed. Easily pocketed battery sizes give a working light of 2 to 3 hours.

Our most satisfactory prototype to date (Figure 2) uses a small cylindrical reflector in which are mounted two miniature krypton bulbs consuming approximately 1.8 watts. Initial testing has confirmed our predictions regarding the required light intensity, and the device produces a dramatic improvement in brightness of reading material in all indoor conditions. The prototype is now suitable for user field testing.

Acknowledgments
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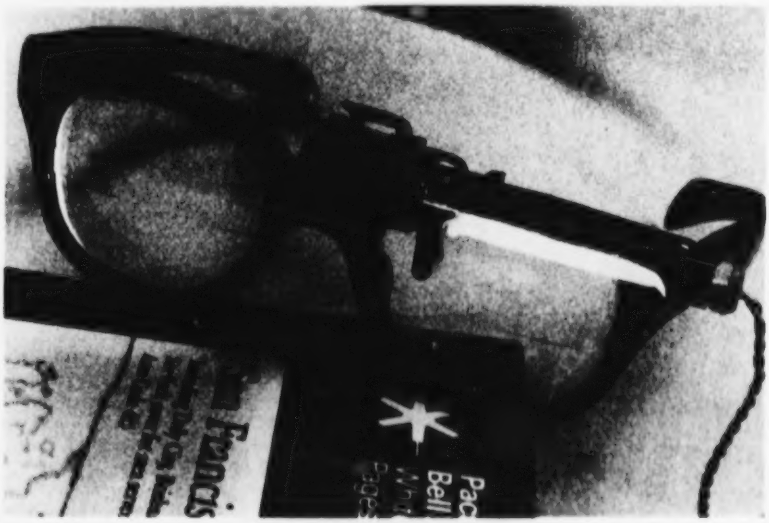

Figure 2. Spectacle-Clip Illuminator

16.2

NATIONAL EVALUATION OF ELECTRONIC TRAVEL AIDS FOR BLIND AND VISUALLY IMPAIRED INDIVIDUALS: IMPLICATIONS FOR DESIGN

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ABSTRACT

A national study of blind individuals who currently use or have used an Electronic Travel Aid (ETA) has recently been completed. The study focused on the personal and environmental factors that relate to ETA use, including frequency of use and users' perceptions of the benefits of ETA's in particular travel situations. The most significant overall finding of the study was the relatively high rate of reported use of two ETA's, the Laser Cane and the Mowat Sensor. The study has important implications for developers of mobility aids for blind persons and individuals who design and evaluate the impact of technology for individuals with handicaps.

INTRODUCTION AND BACKGROUND

Independent mobility is a critical skill for the estimated 700,000 legally blind individuals in the United States. Beginning in the 1950's, a set of mobility aids was developed for these individuals to supplement the travel relevant information provided by the long cane or dog guide. These devices, known as electronic travel aids or ETA's, were active electronic systems that radiated a beam or cone of electromagnetic or acoustic energy into the environment. Upon striking an obstacle, the radiated signal was reflected back to the device and transmitted to the user in vibratory or auditory form. In addition to obstacle detection, some devices were also designed to detect and warn the user of changes in elevation (e.g. curbs, stairs) (1).

Prior to the study reported here, little research had been conducted to evaluate the impact of these ETA's on the travel habits or perceived travel abilities of blind individuals who use them (2). Our study of users and former users provided information about the benefits of ETA use in various travel situations and the reported changes in travel as a function of ETA use. It also provided information relevant to engineering and design (e.g. physical characteristics of the aids and their outputs) of ETA's. Differences between users and former users on personal and environmental variables such as age, age at ETA training, provider of ETA, and living situation were also explored.

METHOD

During the twenty-four month study, 298 blind individuals trained to use Electronic Travel Aids (ETA's) were interviewed by telephone. The interviews lasted approximately one hour, and allowed researchers to obtain data on demographic variables, travel habits, and perceptions of the benefit of ETA's. Each of the participants in the study had been trained to use the Laser Cane, the Mowat Sensor, the Pathsounder or the Sonicguide. In a few instances, participants had been trained to use more than one of these devices.

RESULTS

Demographics

Participants in the study were predominantly male (82%). They were largely middle aged and reported relatively good health, although a third report hearing loss. Few reported having useable vision. As a group, ETA trained individuals had a much higher rate of employment than the blind population as a whole, and more than a third of the employed individuals were in professional occupations. Income levels reflected these employment data.

Training and Use of Mobility Devices

Sixty seven percent reported the long cane as their primary mobility aid (i.e. the aid they used most often in the past year). Primary use of the dog guide and Laser Cane was 14% and 10%, respectively. The sample as a whole rated themselves as having high confidence in their travel ability in unfamiliar areas (75%). Eighty four percent reported at least some travel in unfamiliar areas.

All participants were trained with one or more of the following devices: Mowat Sensor (40%), Sonicguide (33%), Laser Cane (25%) or Pathsounder (2%). Seventy seven percent of our sample reported that they were well prepared to use their ETA, and 37% of the participants reported the device was very easy to learn.

Table 1 shows usage reported over several time frames as a percentage of the number trained to use each aid. Note that the Pathsounder has a very small N in comparison to the other aids, and thus percentage data from the Pathsounder is somewhat misleading.

The reported rate of use was substantially higher than the expected rate reported by a group of 145 O&M instructors in a previous survey.

The situations where ETA use made a big difference in successful travel for 50% or more of the users were:
Avoiding obstacles at body level
Avoiding obstacles at head level
Assessing distance and direction of objects
Avoiding pedestrians in a crowd
Locating a door to a building

TABLE 1

Aid Type	Number Trained		Per Cent Reporting Use in Last	
		3	30 Days	180
Mowat Sensor	123	35%	**59%**	78%
Sonic Guide	109	13%	**25%**	40%
Laser Cane	75	53%	**65%**	69%
Pathsounder	10	10%	**20%**	60%

DISCUSSION AND CONCLUSIONS

A relatively large number of Laser Cane and Mowat Sensor trained individuals reported they still use their ETA. In general, they reported that aid use was associated with more rapid travel and with greater ability to detect and avoid obstacles, particularly at head and body level. Use of an ETA did not appear to be related to how well one knew an environment, as the devices are reportedly used frequently in both familiar and unfamiliar areas. Safety, confidence, and frequency of independent travel in an unfamiliar area were generally reported to increase at least moderately when our users began using the ETA. In response to the open ended question "What is the one thing you like best about using an ETA" the three most common answers were object detection, increased independence, and improved mobility (safety, ease of travel).

It is clear from these data is that users believe the aid provides substantial benefit in a number of areas which are critical to successful independent mobility, and, taken as a whole, users seem to be a relatively confident and independent group of travelers. In regard to differentiating users from former users, one finding of interest had to do with the means by which the ETA was purchased. Significantly more users than former users purchased the aid on their own using their own funds. No differences between users and former users were found on ratings of training quality or ease in learning to use the device, nor did veterans and non-veterans show different patterns of use.

In regard to design issues, both users and former users reported the aid to be physically comfortable. Too little information for the effort, awkwardness, and weight and bulkiness were typical responses of former users when questioned about reasons for discontinuance. These responses have implications for modification of existing aids or design of new ones.

Evaluation of technology to determine acceptance and perceived usefulness of end users is essential This study provides a model for evaluating the design and implementation of electronic travel aids for blind persons. We believe it may serve as a model for assessment of other rehabilitation technology as well.

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16.3

TACTILE AND AUDIO TELEPHONE CONSOLE MODIFICATION FOR THE VISUALLY IMPAIRED

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INTRODUCTION

Significant obstacles remain for the visually impaired individual seeking employment as an operator of equipment that provides feedback in a visual format. Recently, it has been shown that complex visual information can be translated for interpretation using tactile senses. At typical workstations, however, simple visual information from equipment may produce insurmountable barriers to the visually impaired individual. Telephone systems, calculators and copy machines often combine simple audio and visual cues. Unfortunately, both types of cues must be sensed before the information can be interpreted.

A totally blind telephone dispatcher worked for several years using a simple telephone system with audio information only. Increasing demand forced employers to install an advanced telephone system providing extensive use of visual cues for proper dispatcher operation. This paper will describe a system designed to modify such a telephone by replacing visual cues with tactile and audio cues. The design does not require alteration in the telephone system circuitry and can be used by the sighted operator in the ordinary manner.

METHODS

The telephone system is the Harris Lanier Renaissance Series XXXII™. The attendant console performs many functions but not all are necessary to fulfill the dispatcher's responsibilities. Four incoming lines are each represented by a flashing LED and a brief tone. The dispatcher must answer one incoming line at a time and transfer the call to a desired extension. After transfer, the operator proceeds to answer the next incoming line. Twenty-four extensions are used at this time and seventy-six more are available for future expansion. Each extension is represented by a backlighted number on the console panel. Three modes are represented by the backlighted number. An inactive light represents an open line, an active light represents a busy line, and a flashing light represents an extension that is not to be disturbed. The dispatcher must know the status of a given extension in order to take proper action on incoming calls.

The design constraints included inaccessible telephone circuitry and the need to make the system available to sighted operators in the normal operation mode. An external modification was designed to translate the incoming line visual cues to audio signals and the extension line visual cues to tactile cues. The four incoming lines were assigned four different bell sounds from a wall box installed by the telephone company.

The conversion of the extension line cues is accomplished through a system with three major components. A light detection panel is mounted on the telephone operator's console. The panel consists of an array of light detectors and is hinged so it can be folded into place for continuous use by the blind operator or retracted for sighted users. Signal detection circuitry and the power supply are enclosed together and mounted on the floor near the workstation. The tactile output panel has buttons used to represent the status of the monitored extensions and is placed within reach of the operator. The entire system can be deactivated for use by sighted dispatchers.

The extension lights are individually monitored by a phototransistor (MRD 305G, Motorola, Inc.) mounted directly above the light on the operator's console. The signal from the active light is transferred to a solenoid driving circuit. The driving circuit activates a miniature solenoid (SP25-12, Electro-mechanism, Inc.) located on the tactile output console. The miniature solenoids are mounted so that, when activated, they extend a button above the surface of the output console.

Thus, each monitored extension is represented by a button on the output console. The status of the extension represented by the light is directly transferred to the associated output button. An inactive light is represented by a depressed button, an active light by an extended button and a flashing light is represented by a button which alternates between the extended and depressed states.

RESULTS

The current system monitors the eight extensions deemed most important by the operator. The modular design of the circuitry will permit expansion in increments of eight new extensions, up to a total of thirty-two. Expansion will depend upon the skill of the user as demonstrated during an ongoing evaluation period. An additional light detector has been added with an audio cue to detect a call from an extension to the dispatcher. This flashing LED is translated into a piezoelectric speaker tone.

CONCLUSIONS

The combination of cues to stimulate a variety of senses has contributed to the efficiency in operating modern equipment. This project demonstrated the substitution of simple cues from one sensory domain to another. The type of system described is suitable for use in many workstation situations because there is no disruption of normal operation or interruption of complex installed circuitry. Such systems allow individuals with sensory deficits to enter workplaces with existing equipment which must also be used by non-impaired personnel. Expandability of such a design is important so the modification itself does not become a barrier as the skill of the operator increases.

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DEXTER III : A PRODUCT IN HAND ?

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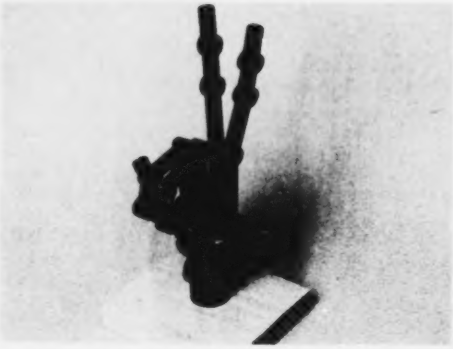
ABSTRACT

Dexter I and Dexter II demonstrated the feasibility of a mechanical finger-spelling hand and its usefulness to deaf-blind persons. They also allowed investigation of the features and design characteristics which would be desirable in a commercial model. Required improvements for Dexter III include eliminating the problems of wires stretching and coming loose, enhancing wrist mobility so all letters can be formed, making transitions between letter pairs more natural and fluid, and generally making the system more rugged. Upstart Robots of San Francisco expressed an interest in joining Smith-Kettlewell in the development of Dexter III. The company's expertise in engineering led them to believe a Dexter hand could be priced competitively with a commercial braille display telecommunication device for deaf-blind consumers.

HARDWARE

Dexter III is being built with the anthrorobotic philosophy of design - that is, by mimicking anatomical detail. As a consequence the hand looks like a plastic skeleton, its joints held together with lengths of nylon cord serving as ligaments, and its digits driven by a system of tendons and tendon-pulling mechanisms which pull the fingers, thumb, and wrist like a human hand. The hand is mounted on a box which contains the tendon-pulling mechanisms and electronic circuitry.

The method of fabricating the joints in the Dexter III hand is different from the standard mechanical practice of providing a cleavage in the members and then pinning the two members together with an axle. The phalanges, or bones of the fingers, are contoured in a way which allows them to butt up against a 1/2 inch diameter cylinder or "knuckle". A nylon cord passes through the phalange and then through the center of the knuckle in such a way that the phalange can rotate around the knuckle but cannot separate from the knuckle. It is actually the sliding of the contoured end of the phalange against the knuckle that provides the articulation.



Hand for Dexter III

Another configuration of "ligaments" (not shown in the photos) will further connect the two phalanges by criss-crossing the palmar aspect of the knuckle. These ligaments will be slack when the finger is flexed and taut when the finger is pulled open, analogous to the human hand.

Using similar construction methodology, the wrist is made of four 1 inch diameter pieces, contoured, stacked at various right angles, and bound together with ligaments. The first piece connects solidly to the driving mechanism box and articulates with a second piece to provide the wrist forward and backward motion. The articulation between the second and third pieces allow the wrist to move from side to side. The last wrist piece serves as a platform for the metacarpals of the palm. These metacarpals provide a support for fleshing out the palm of the mechanical hand in a way that is similar to a human hand. Dexter III will bend its wrist from side to side as well as from front to back, unlike Dexter II.

Also unlike Dexter II, all the driving mechanisms for Dexter III will be housed in the driving mechanism box with nothing mounted to the hand. This allows one to drive the wrist, thumb, and fingers of Dexter III through a system of tendons and pulleys without concern for the physical size of the drivers, and consequently greatly simplifies the design process. The driving mechanisms are a special type of motor configuration designed by Upstart Robots specifically for this type of application.

The mechanical parts of the Dexter III hand are economically manufactured from commercially available plastic (Delrin AF 500) in standard sizes of 3/8, 1/2, and 1 inch diameter rod. This rod is drilled and formed with standard machine shop techniques requiring no unusual contours or demanding tolerances.

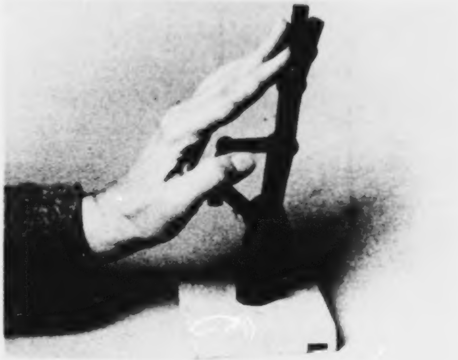
SOFTWARE

Unlike Dexters I and II, Dexter III will move smoothly from one letter to the next, and not need to return to a neutral open hand position between each letter pair. Dexter III, for example, will form the letter "A" (closed fist - thumb at side) followed by the letter "S" (closed fist - thumb in front) by moving just its thumb. To do this smooth transition between every set of letter pairs, the motion control software for Dexter III will move the hand through 26 times 26, or 676, different pathways. Due to this improvement, Dexter III will communicate faster than Dexter I or II, and present dynamic transistion patterns similar to human fingerspelling.

Other new features of the motion control software will include the ability to display numbers and user-controlled fingerspelling speed. Dexter III will communicate to any computer through an RS232 port.

CONCLUSION

Dexters I and II are the gratifying results of the work and talents of two classes of graduate students from Stanford University's Department of Mechanical Engineering in conjunction with Smith-Kettlewell and the Veterans Administration RR&D Center. These earlier versions paved the way for a robotics company to quickly start design of a production model robotic fingerspelling hand and develop a marketing plan. We believe that Dexter III will add to the small number of products actually aimed at the deaf-blind consumer. The Dexter story is a "living model" of both the iterative process of product development and the transfer of technology from classroom to laboratory to commercial marketplace.



"Reading" the Hand for Dexter III

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THE HAND-TAPPER: A COMMUNICATION AND INFORMATION SYSTEM FOR THE DEAF-BLIND USING THE BRITISH MANUAL ALPHABET

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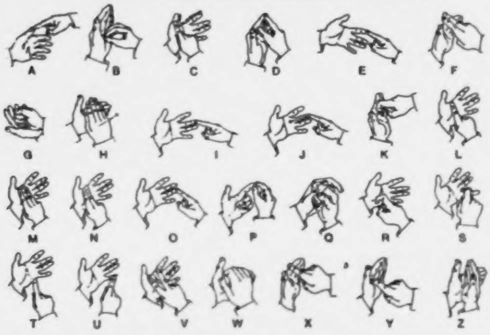
ABSTRACT

The authors describe a communication system for the deaf-blind based on the British manual finger-spelling alphabet. In a new approach a vibrotactile display is used to generate manual-like letters. Applications of the system include interpreting, use of the telephone, access to disc-based literature and news and information from the teletext service.

INTRODUCTION

Equipment which caters for some of the communication methods used by the deaf-blind is already available, consisting mainly of braille devices [1]. Such equipment permits both local and remote conversation, access to written information, and access to electronic news and information services. However 80% of deaf-blind people in the UK, the majority of whom are elderly, are not braille users [2],[3]: the system of communication most commonly adopted by the deaf-blind in the UK is the manual finger-spelling alphabet in which the conversation is spelt letter by letter onto the deaf-blind person's left hand (figure 1).

Figure 1. The Two-Hand UK Manual Alphabet



Two main types of hand-alphabet are in use worldwide. When using a one-hand alphabet the "speaker" makes predefined shapes with the right hand to represent letters. These shapes are actively felt by the deaf-blind person whose hand normally covers the "speaker's". In the case of a two-hand alphabet, however, the "reader's" hand is held out flat and predefined strokes and taps are made to represent the letters.

Work in the US has already led to the development of a device for the US one-hand manual alphabet in which a robotic hand is used to produce the manual symbols [4], demonstrating the feasibility of using machines to generate one-handed finger-spelling. The aim of our research, however, has been to develop a device for use in Britain and the existence of a different manual alphabet in the UK has made possible a completely different approach.

Since the "reader's" hand remains in a fixed position while reading British finger-spelling an alternative method is to devise a vibrotactile display using a matrix of points to generate a discrete form of the alphabet; this approach also has the advantage of being potentially cheap and compact. Such a display has been evaluated and improved by the authors.

DISPLAY DESIGN AND OPTIMISATION

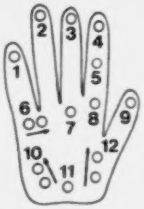
Initially an arrangement of pillars supported by a base-plate was used; solenoids mounted beneath the base-plate are attached to push rods which protrude through the ends of the pillars. The solenoids are fed with chopped dc at 30Hz to produce a clear and localised vibration. Results with this device suggest that the learning time is very short (table 1), confirming that the vibrotactile method presented here can be used to produce recognisable electronic finger- spelling.

Table 1. Number of Letters Learned in 30 Minutes

Subject	*Number of Letters*
DB	10
E W	13
FB	15
KM	20
W H	18
MEAN	*15.2*

Letters which were recognised immediately in more than three quarters of subjects mostly involve motion or are represented by a small number of points: A,B, C,D,E,F,H,I,J,L,O,P,T,U,W,X. The letters P, W, and C were clearly identified by four out of five subjects indicating that the transition to a two-dimensional surface has not significantly affected the readability of these letters.

Figure 2. Layout of Vibrotactile Display



Arrows indicate revised positions.

Following the trials solenoids 6,10, and 12 were moved and letters K,Q,R,S,T,Y, and X recoded to improve readability. A second version of the display was constructed using a purpose built glass fibre moulding, the user's hand resting in a shallow hand-shaped impression in the moulding. Subjects evaluating the new display have indicated that it is substantially more comfortable and easier to use. The improved coding results in significantly less confusion between letters and initial results show that the average learning rate has increased to around 20 letters/30 mins.

OPERATIONAL ASPECTS

An important advantage of electronically generated finger-spelling is the ability to overcome some of the limitations of its human counterpart by providing a feedback path from the user to the display. A method has been devised in which "cursor" keys are used to move through a message or piece of text (table 2). These permit direct control of the reading speed and add a two-dimenstional effect resulting in operation closer to the natural reading process. The arrangement also allows a single letter or part of a message to be reviewed. An autorepeat facility is provided to allow a person who has become familiar with the machine alphabet to read quickly.

Table 2. Display Control Keys

Key	*Alone*	*With RPT Key*
DN	Forward one sentence	Forward a paragraph
UP	Go back one sentence	Go back a paragraph
RT	Move right one letter	Move right one word
LF	Move left one letter	Move left one word
RPT	Repeat last letter	-
START	Go to beginning of text	-
END	Go to end of text	-

THE COMPLETE SYSTEM

A portable system named "Hand-Tapper" has been constructed incorporating the display and "cursor" controls described above. For input a 7 key braille keyboard was chosen on which combinations of keys are pressed to produce letters, numbers, and punctuation marks. This arrangement has the adavntage of compactness and the user's fingers need never leave the keys during typing. The use of braille for input is acceptable since the problems with learning braille are associated with the advanced sense of touch needed rather than the basic code.

The Hand-Tapper consists of a single portable case measuring 18"x12"x2.5" which houses a purpose built Z80 processor card, mains power supply, display and keyboard. Two RS232 compatible serial ports are provided. The DTE port may be connected to a modem, permitting remote computer access via telephone (e.g. to electonic mail or electronic shopping services), back-to-back telephone calls to other suitably equipped people, or calls to a number without special equipment via the RNID Telephone Exchange for the Deaf (TED). The DCE port may be connected to a personal computer for word-processing and other tasks, or to a small hand-held terminal unit with a miniature screen and keyboard for interpreting. The software provides for connection to either of the serial ports and a has configuration mode for setting the baud rates, autorepeat speed, and other parameters. All input and output streams are fully buffered.

SYSTEM EVALUATION

The Hand-Tapper was initially evaluated by the development officer at the National Deaf-Blind and Rubella Association who is himself deaf-blind. Approximately 30 minutes were spent reviewing the alphabet until the letters were thoroughly familiar. It was then possible to have short conversations in the interpreting mode with the system connected to an NEC8401 laptop computer acting as a VDU.

The "cursor" keys were particularly useful in enhancing the operation of the display and the revised coding was considered to be a significant improvement on the original version. No problems were experienced in using the system for telephone calls or for accessing the Dialcom electronic mail service.

DISCUSSION

The present system has demonstrated the feasibility of a portable communication system based on the U.K. manual alphabet and uniquely it allows British finger spellers to communicate in a variety of important situations without the need for a reader or interpreter.

A larger trials group will be established to further evaluate and improve different elements of the Hand-Tapper. The next stage of the project and its applications is shown in figure 3. In addition to the facilities already described a teletext module tuned to the local TV transmitter is used to choose from news, information, jokes and commercials. Books and correspondence are stored on floppy disc.

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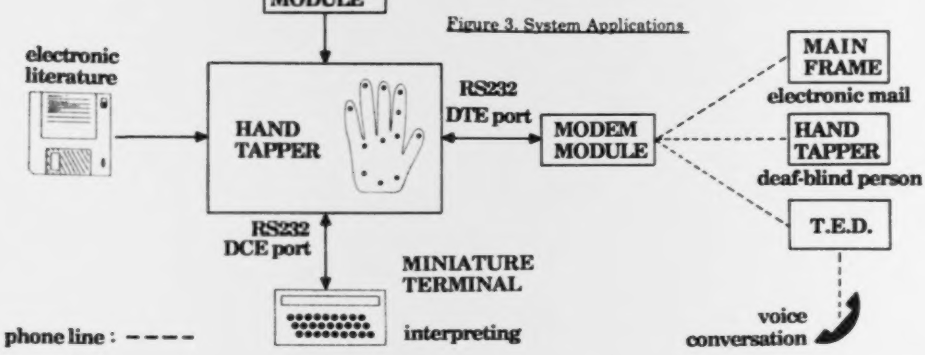

Figure 3. System Applications

Towards More Intelligent AAC Interfaces: The Use of Natural Language Processing

17.1

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Abstract – This paper discusses the use of natural language processing techniques in the design of language interfaces for augmentative communication systems. It presents a new technique called sentence compansion that utilizes both natural language understanding techniques and generation techniques to allow a user to express full grammatical sentences with compressed content word sequences.

Introduction

One of the major goals of augmentative communication research has been to improve the interface between the user and the system. This interface can be viewed as consisting of two components. The physical interface transfers user motor acts into meaningful system input. The language interface provides the user with a set of linguistic units to select from via the physical interface. Improvements to this component of the interface can be obtained from a wide variety of techniques.

Background

At the simplest level, the language interface can be viewed as a structured collection of linguistic units (also called vocabulary sets). Early devices implemented vocabulary sets as simple two dimensional matrices that corresponded to a physical keyboard or to a visual keyboard (e.g., scanning). An extension to this structure that is commonly used today is the incorporation levels. A system with levels incorporates mechanisms to map different matrices to the same physical interface, thus allowing much larger vocabulary sets.

A great deal of effort has been devoted towards further improvement of the language interface. One of the earliest techniques used was optimization of vocabulary sets. Optimization is based on the non-uniform access time to specific units in the vocabulary set. For example, in a simple row column scanning array, the access time to an item is proportional to its distance from the upper left hand corner of the display. Foulds et. al. [1975] utilized this characteristic to design an optimized alphabetic vocabulary set.

Optimization is possible because the human language is structured and rule governed. The keyboard optimization discussed above relied on the fact that in general, letters occur with varying frequencies. Because 'e' occurs more frequently than 'z', it should be more accessible to the user.

Letter sequence frequency has also been exploited in other ways such as in linguistic prediction. Predictive systems rely not only on general information about language, but also on information obtained from the user. A predictive system will dynamically alter the structure of the language interface by offering the user next probable selections based on his/her previous selections [Baletsa et. al., 1976]. Prediction is distinguished from optimization by two important characteristics: 1) the system is dynamic (and in theory more responsive to the user's needs); 2) the system relies on more linguistic information.

To continue making progress in the design of better language interfaces, it is necessary to utilize techniques that take greater advantage of the structure of human language and derive more information from the device user. A branch of computer science called *natural language processing* provides some of the tools to do this.

Natural language processing (NLP) techniques can be distinguished from current methods used in AAC by two major factors. First, most techniques currently used (e.g., prediction) rely heavily on language statistics. While statistics are extremely useful, NLP's emphasis on language rules provide the potential to create more flexible rule based systems. Second, because language statistics are primarily limited to letter constructs (e.g., bigram, trigram, etc.), many of the currently available techniques are limited to word production. Current NLP research is active at all levels of linguistic complexity. Phonology and morphology address how words are formed. Syntax and semantics address how words are put together into meaningful sentences. Finally, pragmatics deals with conversational information that transcends the simple meaning of constituent sentences.

Sentence Compansion

Our first project that utilizes natural language processing techniques involves a new technique that we call *compansion*. Compansion is a term derived from the two words ***compression*** and ***expansion***. In general, the technique allows the user to input compressed sequences of linguistic units. The system will dynamically expand these units into a more "appropriate" representation. Sentence compansion works at the sentence level. The user inputs a sequence of content words, and the system produces a grammatically correct sentence that expresses the user's meaning. It currently assumes that the user's vocabulary set consist solely of words. The technique is best illustrated by an example:

```
INPUT: John Mary go store yesterday
```

```
OUTPUT: John and Mary went to the store
yesterday.
```

Several transformations were performed in this example. First, several words were added to the input sentence (and, to, the). This lessens the total number of selections required from the user. Second, the verb "go" was properly conjugated in terms of plurality (i.e., subject verb agreement) and tense. This type of word modification will help in limiting the size of the user's vocabulary set.

It is worthwhile to note the difference between this technique and other currently available compansion techniques. Abbreviation expansion is a technique that allows the user to input compressed letter sequences as representations of words or phrases [Vanderheiden, 1984]. Semantic Compaction is a technique that allows the user to express words and/or phrases with iconically represented semantic concepts [Baker, 1982]. Both of these techniques use statically defined sequences that must be memorized by the user. If the code is not in the system dictionary, the system will not perform any transformations. Because of the infinite number of sentences that we can produce, these techniques work best at the word or phrase fragment production level

Results

A prototype system has been developed on a Symbolics Lisp Machine using the Common Lisp dialect. It takes as input a sequence of compressed words (correctly spelled) and outputs a syntactically and semantically well formed sentence. The system is limited to input that is contained within its lexicon. The current system has three major functional components.

Semantic Parser – The semantic parser expects as input a sequence of words and builds a semantic representation based purely on semantic information. This is different from most natural language understanding systems in that input is a sequence of content words rather than a grammatically well formed sentence.

Representation Translator – The representation translator is the interface between the semantic parser and the generator. It takes as input the semantic representation of the sentence and outputs the deep the deep structure of the sentence. It uses (among other things) some syntactic features of the input such as word order.

Generator – The generator takes as input the sentence deep structure and outputs a grammatical sentence. It adds function words (e.g., article, prepositions) and correctly modifies root words (e.g., verbs).

At this point, the system is limited in several ways. First, since it relies heavily on the semantic features of words, we have limited the domain of its vocabulary. This is necessary during this initial phase of exploration into the technique. Second, the current implementation runs on a specialized Lisp machine, and we expect that it will be some time before the work is transferred to microcomputer hardware. Since we are in the research stage, we choose not to limit ourselves to widely available technology. We do however expect several practical spin-offs to emerge from this project as it progresses.

One potential advantage of this technique that we anticipate is a reduction of mental load compared to that required for the use of prediction systems. Soede [1986] discussed the problems inherent in the dynamic vocabulary sets of prediction systems. In a compansion system the vocabulary set remains constant (although the output stream does change upon the completion of the compansion process). The mental load effects of this system have yet to be evaluated.

Although we see this is a general purpose technique, usable by many different populations, we are targeting non-spelling individuals as the primary beneficiaries. In systems that are based on sight word vocabulary sets, we would be able to reduce the total word count, as well as save the user from making extra selections. We also think that this approach could be of benefit to symbol-based systems. Many of the words that are difficult to represent symbolically such as verb conjugations (e.g., are, is, am, was, were), and function words (e.g., the, to) would not be necessary. Finally, this technique might find application as a language training tool.

Conclusion

Sentence compansion is just an example of the application of natural language processing techniques. The tools developed in this project can potentially be applied to many other techniques (e.g., word prediction, translators). We feel that this technology will emerge as a fundamental assist in providing future communication devices with a greater degree of intelligence.

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VIC PERFORMANCE - EFFECT OF GRAMMATICAL CATEGORY

17.2

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ABSTRACT

Two studies were carried out to investigate the receptive processing of VIC prepositional phrases by a severely expressively aphasic lady with relatively preserved auditory comprehension and little functional speech or writing. The studies were carried out after 4 and 9 months' VIC training, respectively. In Study 1, errors in prepositions took longer to identify than errors in nouns. In Study 2, prepositions represented by symbols were processed correctly 14 / 16 times, while prepositions represented by spelled words were performed at chance level. At the same time, performance was unaffected by representation of all nouns using spelled words. Results are consistent with findings from other studies of VIC of major differences in aphasics' facility of learning and using symbols as a function of grammatical category.

INTRODUCTION

VIC (Visual Communication) (1),(2) is an augmentative communication system designed for people who are severely aphasic as a result of stroke causing damage to the areas of the brain, usually in the left cerebral hemisphere, which are important for understanding and producing language. VIC was originally carried out using cards and is currently implemented as a program on the Macintosh in which virtual card piles are represented on the screen. VIC use involves mouse-selecting the card pile corresponding to the grammatical category of the concept to be expressed (e.g., nouns, verbs), pointing and clicking to open the pile and display its contents, then pointing and clicking the symbol representing the desired word. The symbol selected is then copied by pointing and clicking on a location in a sentence-building frame.

Studies of training globally aphasic and severely expressively aphasic patients with variants of the Visual Communication System have reported differences common in type, but not degree, to all aphasic patients who have participated in this training. Typically, symbols for nouns are learned and recalled much more proficiently than symbols for any other class of concepts (1),(2).

SUBJECT

Mrs. E., a premorbidly left-handed homemaker and enthusiastic hobbyist (bowling, knitting, crosswords), became severely aphasic as the result of a left cerebrovascular accident (CVA) at age 61. Spontaneous speech, at 18 months post-CVA, when she began training in VIC, consisted of non-referential, fluently produced words and phrases "you know, when!" "come on!" "I can't -- when!" . She was able, with structure, to produce isolated content words (e.g., names of people and objects), although with much-elevated latency and marked dysarthria. Social comprehension was excellent, and overall auditory comprehension was relatively preserved, compared to expression.

Mrs. E. was a quick study, despite never having used a computer before, and at her first session was quickly retrieving object cards from non-initial pages of the object card pile in non-modeled answers to questions about her food preferences. She quickly became proficient in using VIC on the Macintosh to produce sentences in structured situations, and in spontaneous use as well. Because of her high level of auditory comprehension, training in VIC was directed entirely at production, not at reception.

STUDY 1. At 4 months into training (twice-weekly sessions), Mrs. E. was correctly carrying out production of sentences in VIC in response to verbal instructions to describe actions of others and of her own. A set of stimuli was devised to test her comprehension of VIC prepositional phrases and their appropriateness to arrays of objects. The hypothesis was that if Mrs. E. was not simply associating rote-learned symbol sequences with specific arrays of stimuli, she would demonstrate differential responses, in terms of latency and accuracy of judgments, to systematically manipulated features of grammatical and semantic deviance.

MATERIALS. 16 stimulus messages were constructed, each corresponding to the placement of two objects in relation to each other: 2 containers, 4 other objects, placement of one object IN or ON another. 8 stimuli were correct; of the others, 4 contained the wrong preposition and 4 an incorrect object name. Half of the sentences were semantically acceptable, e.g., "PENCIL ON CUP" and half were semantically unacceptable (impossible), e.g., "CUP IN PENCIL".

Messages were constructed on the Macintosh screen, the objects were then arrayed in front of the subject and the screen was turned to face her. She was asked to indicate whether the sentence was correct or not as a description of the array of objects. Responses were tape recorded and timed. If her judgment was that the sentence was incorrect, she was then asked to show where the error was.

RESULTS. Mrs. E. judged correctly 13 / 16 times. She succeeded in identifying all of the incorrect sentences (with a mean latency of 12 sec.). In the case of correct stimuli, she mistakenly judged 3 / 8 as incorrect (mean latency 28 sec.). Noun-errors were responded to more quickly than preposition-errors (7 versus 18 seconds). Correct judgment of error was performed more quickly than correct judgment of correctness (12 versus 31 sec.). Semantically acceptable incorrect sentences were dealt with twice as quickly as inacceptable ones (8 versus 17 sec.).

When asked to identify the locus of the error Mrs. E. did so correctly 7 / 8 times. In the 3 stimuli she judged incorrectly as containing errors, she ascribed the errors once to choice of one noun, and twice to card order errors.

DISCUSSION. The fact that object error-containing stimuli were treated much faster than stimuli whose errors were in the choice of preposition suggests that Mrs. E. first interpreted the noun symbols and checked to see whether they corresponded to the objects in front of her. When there was a failure to match, or an apparent failure to match, she judged the sentence wrong. In cases of correct noun symbols, she then proceeded to interpret the preposition, and construct full semantic representations for the stimuli. In half of these cases this was difficult to do, since the (incorrect) stimulus was also semantically unacceptable, i.e., it described a physically impossible object array. This interpretation is consistent with the finding that object-error stimuli were correctly and rapidly judged (mean time = 7 sec.), semantically acceptable preposition-error stimuli were next-fastest (mean time = 10 sec.) and semantically unacceptable preposition-error stimuli were slowest (mean time 25 sec.).

These findings suggest that at this point in her VIC training, interpretation of prepositions took place as a separate process from interpretation of noun symbols. Indeed, if possible, interpretation of prepositions was avoided altogether.

STUDY 2. Mrs. E.'s evident visuospatial skills, demonstrated by the rapidity and reliability with which she retrieved symbols from among the numerous cards in her VIC "deck" (vocabulary set, which can number up to 240 items), and results of investigations of her spelled word recognition and recall of initial letters of words belonging to specific semantic categories, led to a decision to change the representation of all nouns (people and objects) from pictorial symbols or digitized photographs to spelled words. After about three months of experience with spelled nouns, including functional use of the computer at home for that period, a brief test was carried out in order to determine whether spelling could also be used to represent members of the closed class of prepositions. Prepositions were represented in this test either as spelled words or as symbols coupled with spelled words. The symbol-plus-word is the form which had been used in training.

MATERIALS. 32 phrases were prepared and printed on cards. The phrases consisted of 16 prepositional phrases each represented once by noun, preposition, noun, in spelled form, and once by noun, symbolized and spelled preposition, noun. Four different prepositions (IN, ON, UNDER, BETWEEN) and 10 objects were used. Each card was presented along with an array of 2 objects (e.g., dollar beside box) and Mrs. E. was asked to decide whether the phrase presented along with the objects correctly described the array or not. To minimize the time this test took away from training, no further questions about the stimuli were asked. Half of the stimuli were incorrect in respect to the array, and half were correct, with correct and incorrect balanced between English-only and VIC-plus-English stimuli and order of presentation randomized.

RESULTS. Mrs. E. judged the VIC-plus-English stimuli correctly 14 / 16 times; she judged the English-only stimuli correctly 7 / 16 times, i.e. at a level consistent with chance.

DISCUSSION. At a time at which Mrs. E. was fluently selecting almost 200 nouns represented solely as spelled words from multi-page, 8 nouns-to-a-page displays, she demonstrated a clear difference in her ability to process spelled prepositions versus prepositions represented by VIC symbols coupled with spelling. This result is consistent with the elevated latency demonstrated five months previously in judging sentences which contained incorrectly chosen prepositions. It is also consistent with the difficulty she has continued to show in choice of preposition and in ability to correct incorrect choices spontaneously, which appears to have stabilized at a level consistent with her performance in these tests. At the same time she has reached impressive fluency and speed in her spontaneous VIC conversation.

The finding of quantitatively much greater difficulty in dealing with representing relational, abstract concepts as opposed to referential, nominal concepts, has been frequently replicated, in patients across a variety of severity levels. This suggests that a new design approach may be indicated, which will not impose demands which are unsuited to the preserved abilities of these patients as a requirement for communication.

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A SEMANTIC PARSER FOR UNDERSTANDING ILL-FORMED INPUT

17.3

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Abstract

In this paper we explore the integration of natural language understanding techniques into augmentative communication devices. A semantic parser is described which takes a string of words (chosen from a word board) from the user and tries to identify a semantic interpretation of those words. One goal is to allow the disabled individual to input a compacted message (i.e., one containing mainly the content words of the desired utterance) and eventually have the intended message generated in full. This task requires that the utterance first be understood. Understanding is complicated because we expect the utterance to be largely ill-formed with respect to the normal syntactic rules of the language. The ill-formedness constraint has led us to develop a novel semantic parser which is driven by the possible semantic interpretation of the individual words in the input utterance.

Introduction

This work is part of the compansion project being done at the Applied Science and Engineering Laboratories at the University of Delaware and the AI DuPont Institute. The goal of the project is to allow the disabled individual to input a compressed message containing the content words of his/her intended utterance. The system will take this input, generate a semantic representation using natural language understanding techniques, and eventually generate a well-formed English sentence.

A semantic processor of this type would also be useful in other applications such as a system which translates American Sign Language into English, or a word prediction system, or a system which checks the grammar of a written text.

The semantic processor is concerned with creating possible semantic representations for the words input by the user. We have taken as our semantic representation a case-frame analysis of the sentence based on [2]. Thus the semantic interpreter must: identify the verb of the sentence, identify which constituent is playing the role of the actor, which is the object, instrument, to-location, from-location etc...

Classically the process of constructing a semantic representation from some input words has been broken up into two phases [1]. In the first phase a grammar of English is used to generate the deep structure representation of the sentence. The assumption of this phase is that the sentence is syntactically well formed. Next, semantic rules are applied to this deep structure in order to generate the semantic representation.

Due to the potentially severe syntactic ill-formedness of our user's input, this approach was not feasible. We have accordingly focused our efforts on understanding which does not rely on a syntactic phase [4].

Methods

Our work is based on that of Small and Rieger [3] who designed a "word expert parser" which basically allowed each individual word in the input to contribute to the overall meaning of the sentence individually. However, the meaning of an individual word in isolation (i.e., the role it plays in the sentence) is ambiguous. For instance "John" may either play the role of an actor or an object in a sentence. The words in a sentence, however, are mutually constraining. Thus the words in a word expert parser may communicate with each other so that the correct interpretations can be identified. For instance, the verb "laugh" requires an animate actor and no object. Because of this, "John" must play the actor role with respect to the verb "laugh".

We can think of the words in a word expert parser as working in a bottom-up fashion – each individual word is declaring what role it can play and all of the words are trying to fit together into a well-formed semantic structure. In our system we augment this bottom-up processing with a top-down component which uses more specific semantic structures (associated with domain contexts) which look for words to fill their roles. In our system, groups of words which naturally occur together in conversation are divided into *contexts*. A particular word may occur in more than one context and may contribute a different meaning in each. For instance, the word "Boston" might be associated with the "airline flight" context as well as with the "city government" context. The "flight" context contains rules that say that "Boston" can fill the role of either TO-LOC or FROM-LOC. On the other hand, rules in the "city government" context might allow "Boston" to fill the ACTOR role (as in "Boston instituted a law making it illegal to...").

In order to implement different words contributing different meaning in different contexts, associated with each specific context is a set of semantic rules whose preconditions specify specific words. The actions of the rule will build pieces of semantic representations for the word which are specific to the particular context. The semantic rules serve the purpose of bottom-up interpretation of the input sentence in each specific context.

In addition to the context adding different interpretations of the individual words, each context has associated with it expectations (which we call frames) about an overall semantic structure for a sentence in that context. These semantic structures may be more specific than a general semantic structure. For instance, in the flight domain, to and from locations must be cities with airports (while they may generally be any place). The frames associated with a context "look" for words in the input which can fill their roles. They serve to further disambiguate the role played by particular input words since they specify constraints on the role fillers imposed by the domain (e.g., in the flight domain Newark, Delaware must not normally be a to or from location since it doesn't have an airport).

In order to take advantage of the frames and specialized word meanings associated with a context, the context of the sentence as a whole must be identified. The sentence context is determined by taking (something like) the intersection of the contexts of the individual words. That is, we choose that context which every word of the input utterance is a part of. The sentence context lends a top-down orientation to the semantic processing by identifying a set of frames which are basically skeletons of semantic structures. Each frame corresponds to a possible final semantic structure for a sentence under the context. The semantic interpretation for the individual words must be fit into the frames for the specified sentence context(s).

Conclusions

In this work some natural language processing techniques have been applied to the design of an augmentative communication device. Our goal is to speed up the communication rate of the user by allowing him/her to type in a very sparse, ill-formed message. Our system first attempts to "understand" the input by creating a semantic representation and then "generates" syntactically well-formed sentences.

The semantic processor is innovative in that it does not rely on syntactic clues. We expect this aspect of the system to be particularly useful in cases where the user has limited or diminished linguistic skills. Instead the processor operates in a bottom-up fashion combining possible semantic interpretations of the individual input words into a semantic structure. At the same time, it works top-down from skeletons of semantic structures associated with the domain context.

Acknowledgements

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DATABASE DESIGN FOR STORING AND ACCESSING PERSONAL CONVERSATIONAL MATERIAL

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ABSTRACT

Communication systems for non-vocal people which can store and output entire phrases would seem to offer much help in assisting the user to make conversation, but their potential has not been realized. With a large number of phrases there are severe problems in remembering what is stored and how to access it. We have investigated methods of designing intelligent systems which would relieve the user of much of this effort. We are currently developing a prototype system called TOPIC, to guide a user through topic-discussion conversations. This paper discusses the database design which is employed in the TOPIC system, and the controlling program which interfaces with the database and the user.

HELPING THE USER TO TAKE PART IN FREE-FLOWING CONVERSATION

One method for increasing the speaking rate for nonvocal users of communication systems is to store whole phrases which can be called up for speaking out at the appropriate time (1). Such phrase storage should offer considerable help in making conversational interactions possible, but such systems have not realized this potential. There are inherent difficulties in accessing a large number of stored conversational phrases. Users have found that it is difficult to remember either where each phrase is stored, or the access paths to these phrases provided by current systems.

We are investigating approaches to this problem which involve designing the system to relieve the user of as much as possible of the access process.

The CHAT system, which has been developed at Dundee University, is a prototype communication system which helps the user to negotiate the more formulaic, and hence predictable parts of a conversation (2). Predictable and formulaic conversation sequences make up a good deal of the kind of everyday verbal interaction which has as its purpose maintaining social cohesion. It is important for nonspeaking people to be able to participate in this type of conversation as well as to be able to convey information (3). CHAT has been used in a number of experimental and clinical situations and has shown great promise in increasing the effectiveness of social interactions.

BUT WHAT DO YOU SAY AFTER 'HELLO'?

We are also developing another prototype system which is intended to assist the user to take part in the more free flowing topic discussion portion of a conversation. This system is called TOPIC — Text OutPut In Conversation.

The principle on which TOPIC is based is that a significant amount of topic-based conversation is reuseable (4). One particular example of reuseable conversation is recent family news which we all keep ready in our minds to call on whenever we are asked how the family is getting on. Another is a current joke which we particularly like. Many other examples exist which are more context dependent or are based on relationships with particular groups of friends and acquantances.

TOPIC consists of a database, database management software, and intelligent user interface. The central module of the TOPIC prototype is a program which interfaces with the user, and with the database of conversational material. The database software used is a commercially available product, which is free-format and supports interfaces to programming languages.

This is a rather unusual application for database software, and in developing TOPIC we have derived a number of guidelines on how such a database should be structured, and how the controlling module could help a user navigate through it to produce conversation. These are outlined in the sections below.

STRUCTURE FOR A DATABASE OF CONVERSATIONAL MATERIAL

A free format database is desirable as this allows the database software to hold text easily, and to be relational in character; that is, any two records are linked if they share a common field, so records of different types can be stored together. Using this structure it has been possible to model the different types of conversational acts with text held in different types of record.

In the current implementation of TOPIC each conversational contribution is held in a separate record. One field of the record holds the text itself. This can be as much text, or as little, as is required. Other fields hold a unique identifying number, subject descriptors, speech act descriptors, and a frequency of use counter.

Database design

An example of a record from the database is given below :

IDNUM: 179
SUBJECT: books, astronomy, science, TV
SPEECHACT: requestinfo, inform, disclose
FREQ: 3
TEXT: Did you see the TV programme about space exploration recently?
It was very well done.
There's been a book written based on the series which I plan to buy.

SEARCHING THE DATABASE

A number of search strategies can be used to retrieve records held in this way. Searching can be done on the basis of speech acts, by topic descriptions, by words contained in the text, and by the frequency with which a piece of text has been used in the past. Any combination of these specifiers is also possible.

The purpose of TOPIC is to facilitate the process of finding and outputting text in conversation. Although it can offer the user tools for finding the appropriate piece of text in the database, TOPIC also attempts to predict what the next piece of text is likely to be. This is based on the principle of the reuseability of conversational material and the structures developed in the original CHAT software.

TOPIC communicates with the user via a window of predictions. When the user outputs an item (usually through a speech synthesiser), TOPIC shows the user a set of candidates for the next utterance. The algorithm used to select candidates is based on their frequency of use, semantic information supplied by the present record's descriptors, and on possible 'scripts' which the user may wish to follow. (A script in this sense is a stereotypical series of utterances, which can be considered as a unit. Example scripts might be buying something from a shop, telling about your Christmas holidays, or explaining how to get your wheelchair into a car (5)).

FUTURE RESEARCH DIRECTIONS

As well as further work on the current implementation of the TOPIC prototype, we are also interested in exploring the potential of hypertext as a host for TOPIC like systems. Hypertext is a way of storing and accessing material which encourages the creation of multiple links between each stored item and other items. This could offer a structure which was highly personal in its form, and which could better model the way that conversational material is stored and recalled by unimpaired speakers (6).

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17.5

TOWARD A COMMUNICATION DEVICE WHICH GENERATES SENTENCES

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Abstract

Sentence generation will be an integral part of future augmentative communication devices. By employing natural language processing techniques, we hope to enhance the speed, flexibility, and ease of use of current word-based systems. In this paper, we discuss the generation component of our "compansion" system, which expands compressed messages entered by the user into full English sentences. The two phases of this component are (1) the translator, which converts a semantic representation of the message into a syntactic "deep structure" representation and (2) the generator, which takes this "deep structure" and uses a functional unification grammar to produce a complete English sentence. Because of this modular design, the generator is independent of whatever semantic representation is used; thus, it could be easily adapted to other systems (e.g., sign language translation) through the use of a different translator.

Introduction

Sentence generation will be an important component of many communication aids in the future. For instance, it is one component of a system which takes compressed input from the user and generates full well-formed sentences, it could be used in translation devices (e.g., ASL to English), it could be used by a system which improves written English by parsing the writer's prose and then generating better formed sentences when necessary.

In this paper we describe one such generator which is currently used in the "compansion project" at the Applied Science and Engineering Laboratories at the University of Delaware and the AI DuPont Institute. The goal of the project is to allow the disabled individual to input a compressed message containing the content words of his/her intended utterance. The system will take this input, generate a semantic representation using natural language understanding techniques, and eventually generate a well-formed English sentence.

A sentence generator must take a semantic representation of an utterance which is independent of any particular natural language (e.g., English) and translate this representation into an English sentence. We have broken the process into two phases. In the first phase (the translator) the elements in the semantic representation will be replaced by their language specific instantiations. In the second phase (the generator) a grammar of English syntax will be used to order the sentence elements and add proper word endings and syntactic elements so as to output a legal English sentence. In this paper we focus on the generator phase, adding reference to the translator phase in order to point out its novel features.

Background

Input to a generation component is the semantic structure of the sentence to be generated. E.g.,

```
((actor = John)
 (verb = hit)
 (object = ball)
 (instrument = bat))
```

Notice that this information tells what role is played by each content word of the sentence, however, it gives no indication of how the items can be realized in English. In fact there are several valid English realizations of the above information (each of which requires lexical items to be added for syntactic reasons): "John hit the ball with the bat", "The ball was hit with the bat by John", "John used the bat to hit the ball", etc... Of course, one can also construct many non-sentences using the items from the semantic structure (e.g., "John hit ball bat"). The job of a generation component is to enable the generation of the valid orderings while blocking the generation of the invalid ones.

One approach to the sentence generation problem, which is unsuitable for our purposes, is to encode a grammar of English which utilizes the normal syntactic rules and categories of the language (e.g., a sentence is a noun phrase followed by a verb phrase, a noun phrase is a determiner followed by a noun). To use such a component, the translator would have to be responsible for making very language specific decisions about the realization of the semantic input (e.g., the input should be translated as an active sentence whose first noun phrase is John, etc...). Once this is done the input from the translator must be re-ordered to conform to the valid rules of English as embodied by the grammar. This process is much like the reverse of a basic parsing algorithm such as found in [4,1].

The Functional Model

Rather than following the above approach, we have chosen to implement our grammar using the function unification model [2,3]. In this model the functional categories (like those found in the semantic input) may be part of the grammar just as the syntactic categories are. Hence the grammar may specify that a sentence is an actor (which is realized as a noun phrase) followed by a verb, followed by an object, etc... Such a specification allows the translation component to have less language specific information. It still must give actual words and perhaps even identify the category of the roles contained in the semantic structure (e.g., that John can be realized as the noun phrase "JOHN"), however, it need not know any language specific ordering rules (such as the difference between active and passive sentences).

Unification and Generation

In addition to the functional nature of the functional unification model, the model is unique in that it is based on *unification*. Very simply, unification is a formal process which takes incomplete information from two different sources and combines it into one, complete, package of information (provided that no information from one of the input sources contradicts that in the other).

The functional unification model views generation in this way. The two sources of information are (1) the input which contains information about the functional role and lexical realization of the pieces of the sentence to be generated but contains no information about how that information should be ordered or what additional lexical items might need to be inserted in order to make a valid sentence, and (2) the grammar which contains information about several proper orderings of functional features as well as when and where additional lexical information might be needed for purely syntactic purposes.

Notice that both of these sources of information are incomplete alone – neither contains enough information to generate a valid sentence. Yet each has what the other needs. By taking them in combination, the valid alternative orderings of the functional features provided by the grammar can be narrowed to the one compatible with the input features, proper lexical (content) words from the input can be inserted into the chosen ordering, and additional (syntactic) lexical items can be added according to the grammar. The unification process combines the two sources of information and the result is a valid English sentence which realizes the input semantic structure.

Conclusion

In this paper we have described a functional unification model for doing sentence generation. The model is attractive since it allows input to the actual generator to be in functional rather than syntactic terms. This allows the translator (which takes the input semantic structure and adds necessary language specific information) to work with minimal knowledge of English syntax. In addition, the model works on the principle of unification which is very attractive for generation purposes. Both the generator's grammar and the input from the translator are viewed as partial descriptions of the sentence to be generated. The grammar contains a specification of legal English sentences but contains no information about any particular sentence to be generated. The input contains specifications for the particular sentence to be generated, but no information about rules of English syntax. The unification process combines this information to generate a valid sentence.

Acknowledgements

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AUTOMATED ORTHOPEDIC SHOE LAST PRODUCTION

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ABSTRACT

Custom-molded shoes require a last to be made prior to the fitting of the upper leather patches and the soles to the last to make a shoe. This paper describes an integrated system of computer-aided techniques for the design and manufacture of the shoe last for the purpose of making custom-molded footwear.

INTRODUCTION

The shoe last is unquestionably the single most important element in shoe making because it provides a rigid base for the shoemaker to stretch the upper material around it and to attach the soles to its bottom to form the shoe. The making of a last traditionally requires some kind of casting techniques such as the univalve and the bivalve techniques (RTI88). The casting is made around the actual foot of the patient , then a product like liquid last is poured into the casting to produce a positive cast of the foot. This cast is further modified to represent the volume inside the shoe that this foot is intended to wear. Typical shape modifications include adding a toe box, narrowing the heel section, and some other desirable features for the last.

Because it is a complex object, the making of a last usually requires skill, good judgement, and years of experience from the part of the shoe maker. Also it is a time consuming task , hence costly.

On the other hand, scanning technology is now available to digitize the foot and, through the application of Computer-aided Design and Computer- aided Manufacturing techniques, to actually produce the last in a shorter time and in a more accurate way than the traditional manual technique of last making. This paper introduces to the readers an integrated system of foot scanning, last design, and last machining that may help improve the quality and productivity of the shoe last fabrication process. This system is currently being developed at North Carolina State University and the University of Missouri in Columbia. The faculty in charge of this project has a varied background in Computer Science, Electrical Engineering, Mechanical Engineering, and Industrial Engineering.

INTEGRATED CAD/CAM SYSTEM

The elements of this system are shown in figure 1.

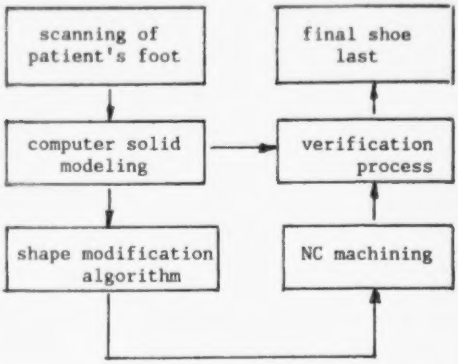

Fig.1 Elements of the CAD/CAM system for shoe last production

Scanning of patient's foot

The scanning was done by two commercial systems respectively known as CENCIT$^{\text{TM}}$ and CYBERWARE$^{\text{TM}}$.

The CENCIT system relies on a number of solid state video cameras (from 3 to 6) located at equal angular distance around the object. Strobe lights in synchronization with the cameras are used to illuminate the object. The result of the scanning is usually three 120-degrees views of the object, each view containing a matrix of 200x256 grid points and corresponding heights.

The CYBERWARE system uses a stereobiometric range finding technique to scan its object with a digitizing camera that rotates around the object. This scanning device is capable of generating up to 256 latitudes and 512 longitudes to digitize the object. Either system provides an adequate supply of data points to carry out the remaining tasks in the footwear project.

Computer Solid Modeling

In view of the huge amount of data points available from the scanning systems discussed previously, the handling of the computer image through the standard wireframe representation was discarded. Instead, a parametric representation of the surface using the Coons's patch (Coons67, Faux79) was adopted. A full discussion of this latter approach, and its implication over various shape modification techniques, can be found in Mcallister88.

Numerical Control Machining

Two major approaches have been tried respectively at North Carolina State University (NCSU) and the University of Missouri (MU). The team at NCSU treats the last surface in terms of Coons patches then applies the APT (Automatically Programmed Tooling) processor to generate the Numerical control codes for their machine tool. The team at MU uses the data points directly and programs the tool to move from point to point. In either approach, a critical problem to be resolved is the issue of tool interference, that is the tool by virtue of its size may unintentionally cut into the profile of the surface being generated. Various techniques have been tried to deal with this problem, using the approaches proposed by Faux79 and Saunders84.

For cylindrical work like the shoe last, the use of a rotary table is required. The programming aspect of this piece of equipment is another important factor for consideration. Essentially, the various ways of programming the motion of the rotary table can result in four different machining approaches, notably contour machining, cartesian machining, constant theta per pass (tetha is the angular diaplacement of the block), and constant longitudinal machining. Each machining approach is associated with some advantages and disadvantages as discussed in Bao89.

Verification

The object resulting from machining may not necessarily be a true reproduction of the design model. Therefore a verification process is required to check for size and shape discrepancies between them. This aspect of the project is being done at North Carolina State University.

CONCLUSION

This paper has briefly introduced the components of the automated orthopedic shoe last production system being developed at North Carolina State University and the University of Missouri for NASA's Technology Utilization Office in Hampton, Virginia, the sponsor of this project. Ultimately the system will be delivered to the Veterans Administration for field test.

Actually the scope of the project is broader than what transpires from this paper. Other modules that have not been discussed in this paper include a supervisory system that will be capable of handling both administrative and personal data and technical data such as graphics files and numerical control machining codes. Detail of this work is available in Rasdorf89. Also, the design and production of the bottom elements of the shoe such as the pads, the wedges, the heels, and the soles form another module to be added to the system. The integration of all modules, administrative and technical, still remains one of the primary goals of this project.

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Department of Industrial
Engineering, The University of
Missouri-Columbia, Jan 1989.

CONSIDERATIONS IN OPTICAL DIGITIZATION OF LOWER LIMB SEGMENTS FOR PROSTHETICS CAD/CAM

18.2

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ABSTRACT

Design considerations for optical scanners based on photoreflectometry for input to lower limb prosthetics computer-aided design and computer-aided manufacturing (CAD/CAM) systems are discussed. Test results with several below-knee (BK) amputee test subjects are presented.

INTRODUCTION

A number of computer-aided design and computer-aided manufacturing (CAD/CAM) systems are currently being developed and clinically tested in lower limb Prosthetics. From this research, it has become apparent that new, faster, more accurate and comprehensive techniques and devices for measurement of patient information must be developed for input to prosthetics CAD/CAM systems.

BACKGROUND and DISCUSSION

All of the prosthetics CAD/CAM systems that have been, and are being, developed require quantitative information about the spatial distribution, surface topography, and relative spatial alignment of patients' limbs.

At present this information is either obtained manually or from semi-automated, electro-mechanical measurement devices. Of the various devices and techniques for limb segment characterization, optical scanning systems based upon photoreflectometry show the most promise. Before such devices can be realized, however, a number of performance requirements specific to lower limb Prosthetics must be considered. These include establishment of performance bounds for system resolution, accuracy, scan time, object capacity, operating environment, and CAD/CAM system interface requirements.

The ability of any sensor to measure the surface topography, spatial distribution, and relative alignment of an object, such as a human limb, may be evaluated with respect to two quantities. The first is the sensor's resolution, i.e., the extent to which the sensor is able to detect and measure changes in the surface contours of the object. And the second quantity is the sensor's accuracy, i.e., the amount of error present in the sensor's estimates of the location of a given point or points on the object.

In applications in lower limb Prosthetics, most objects to be scanned fall within a cylindrical space approximately 250 mm in diameter and 460 mm in height. In BK prosthetics applications the areas exhibiting the sharpest contour variations, viz., the hamstring tendons, patellar borders, the tibial tuberacle, the tibial crest, the condylar apices, and potential tissue anomalies such as scars, neuromas, and cysts, are also the most stress intolerant, and therefore also require the greatest estimation accuracy. To resolve a contour variation of Δx mm, a spatial Nyquist sampling rate of $f = 1/\Delta x$ samples per mm is needed. To achieve a curvilinear estimation accuracy of Δx mm for an object of approximate cross-sectional radius r, requires sampling every
$\theta = \sin(\Delta x / r) \approx (\Delta x / r)$ deg at each cross-section. Exact error tolerance values remain to be determined, but preliminary results indicate that $f = 1$ sample every 2.0 mm and $\theta = 3.0$ degrees should be sufficient.

Optical scanning systems based upon photoreflectometry, in which a point, line, or plane of light from a laser light source is projected onto an object and the light reflected measured and used to estimate the surface contours of the object, are felt to have the greatest potential as input devices for prosthetics CAD/CAM systems. Such devices are limited in resolution and accuracy by (1) the absorptivity and scattering characteristics of the scanned object's surface, (2) the wavelength of the light source, (3) the resolvability of the photodetector used in the system, and (4) the signal-to-noise ratio (SNR) sensitivity of the sensor photodetection and measurement circuitry. In prosthetics applications the resolution and the SNR sensitivity of the photodetector are the primary factors that determine the resolution and accuracy achieveable by the scanner. Scanning systems with photodetectors incorporating charge-couple-device arrays can achieve submillimeter resolutions and accuracies. To increase the resolution and accuracy much below 0.5 mm, however, exponentially increases the system cost and the data acquisition and processing times required.

Increased data acquisition and processing times introduce additional constraints because of "noise." For the contour variations encountered in the lower limb segments of humans and at the resolutions in question, signal quantization noise should introduce less than 0.5 mm error. The magnitude of the errors arising from the other major source of noise, viz., subject movements, is not known exactly.

Errors from "movement noise" increase as the resolution and the size of the scanned object, and hence, the scan time increases. There are a number of possible sources of movement noise, e.g., postural shift, postural sway, myoclonus, physiologic tremor, senile tremor, resting tremor, postural tremor, toxic tremor, intention tremor, etc. All movement noises, though, lie in the frequency range 0 - 15 Hz, so scanning at rates with periods faster than 0.07 seconds could potentially eliminate this source of error. For the object sizes to be scanned and the resolutions needed in lower limb Prosthetics, however, this would require data acquisition and throughput rates that would raise the cost of the system exorbitantly. Therefore, a compromise must be made.

For millimeter to submillimeter scan resolutions, and for objects lying in a 250 mm by 460 mm cylindrical space, the scan times required should lie between three and twelve seconds. With the exception of postural shift, postural sway, and myoclonus, movement noises are relatively low amplitude disturbances, and therefore should not introduce large errors. Experimental trials have indicated that large errors from patient movements, especially postural shift, postural sway, and myoclonus, can be significantly mitigated through introduction of an appropriately designed patient measurement/scanning fixture. If further movement noise mitigation is necessary, stochastic filtering for jitter supression can be introduced. Preliminary trials scanning several BK amputees using a modified AK measurement/casting stand have not shown errors from movement noise to be a significant source of error.

Another extremely useful feature in limb segment characterization is the capability of marking selected points in the digitized measurement file for subsequent identification of limb segment features, tissue anomalies, etc. This is easily accomplished in photoreflectometric systems through the use of absorptive (black) markers selectively positioned on the limb prior to scanning and subsequent post-processing of the resulting measurement file with an appropriate pattern recognition scheme.

The last two criteria that must be taken into consideration are:
(1) operating environment requirements, and (2) prosthetics CAD system interface requirements. Ideally, scanning systems should be capable of operating in a typical prosthetics clinical environment. This means that they should operate reliably, with little maintenance and without electrical or mechanical hazard on standard electric line current, under ambient lighting, temperature, and dust conditions. Scanning systems should also be capable of producing measurement files for input to a variety of computer platforms and prosthetics CAD/CAM systems. This latter requirement is largely a matter of developing appropriate software for file format transformation, as software and hardware packages currently exist enabling communication between most micro- and mini-computers and workstations.

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EVALUATION OF A LASER SCANNER FOR SHAPE SENSING BKN AMPUTEES

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ABSTRACT

A laser scanner which produces surface profiles of casts and residual limbs from below-the-knee (BKN) amputees was constructed and evaluated. The scanner consists of a turntable mounted laser to define a surface profile line, a CCD video camera to view the profile, and a special video processing board to extract profile data. A microcomputer controls data acquisition and transforms scan profile data into a three-dimensional (3D) numerical description of the surface. The 3D data is then modified and sent to a numerical controlled machine for fabrication of models.

INTRODUCTION

There is a need to provide an accurate mathematical description of the surface of the residual limb BKN amputees to aid in the computer design of prosthetic sockets (1-3). Additionally, there is a need to catalog and study the shapes of scanned limbs at different times, such as before each fitting. Analysis of 3-D surface data provide the potential to improve current methods and practices of prosthetic design. A single laser and a single video camera have been used to acquire surface data as profiles utilizing a scanning procedure (4). To scan more complex structures, multiple laser beams and/or multiple cameras are required (5). The laser scanning device was specifically designed to account for much of the variability of shape and geometrical complexity of BKN residual limbs (6) and produce scans in a cost effective and timely fashion.

BACKGROUND

The operation of the laser shape sensing device is based on oblique observations of a laser line projected onto the surface of an object. A laser beam is projected as a line to establish a reference place passing through the axis-of-rotation of the turntable. The intersection of the beam with an opaque object forms a profile line along the surface of the object. The profile line is viewed obliquely by a video camera. The intense illumination of the laser beam facilitates detection of the profile data within the video signal. Video scan coordinates (scan line, position along scan line) of each point along a profile are determined and used to determine true spatial coordinates. This is due to the positional encoding afforded by oblique viewing. Surface geometry dictates that viewing angles between 40 and 60 degrees be used for most body surfaces to minimize obstruction by adjacent surface structures while maintaining a reasonable degree of positional encoding.

For 3-D data acquisition, multiple profiles are acquired around an object with the laser and camera mounted on a turntable and the laser beam projected through the axis-of-rotation. The angular coordinate of each profile point is determined by the turntable position. Acquiring data while the turntable is rotated about a centrally mounted object produces a set of profiles describing the surface of the object. This scanning method produces raw profile data which is subsequently converted to cylindrical coordinates (radius, angle, and height) on a point-by-point basis. A group of profiles acquired with sufficiently small angular increments provide an accurate 3-D representation of the surface of an object.

A complete scan on a BKN stump can be acquired in under 10 seconds with the current model of the laser scanner. Scans encompass a 360 degree sweep about the stump. Profiles can be obtained every 1 degree if desired; but, we have chosen to use a profile spacing of 4-6 degrees because it yields 60-85 profiles which are currently suitable for subsequent processing. Each profile contains approximately 200 samples from the top to the bottom of the stump.

METHODS

An alignment/calibration jig was used to assess absolute accuracy of the scanner in locating points in the radial and height directions. This was accomplished by positioning the jig at radial positions of -0.25, 1.25, and 2.75 inches and height positions of 4 to 12 inches in 1 inch increments were used. This provided 27 reference marks spread throughout the allowable scan region. The position of each of the 27 points was calculated and compared with the known physical locations of the reference marks.

To test the positional reproducibility of anatomical marking in a realistic setting, surface locations were recorded for three widely spaced surface reference marks on a BKN cast at three different orientations of the cast. The cast was removed and repositioned between each of the three orientations. These orientations provide a large angular difference (116 degrees) between positions 1 and 2 and a small (59 degrees) angular difference between positions 2 and 3. The surface marks were chosen to yield distances between each of about 3.5 to 4.0 inches. 3-D locations (x, y, z) of each surface mark was determined using the horizontal video cursor, the laser line, and the turntable orientation to input raw data positional information. Distances between the surface reference marks were calculated for each position of the cast and used to assess reproducibility of anatomical marking.

RESULTS

The positional accuracy test yielded a mean positional error ranging from 0.02 in. near the turntable axis to less than 0.01 in. at a radius of 2.75 in. No dependence on height was observed.

The anatomical marking test yielded a standard deviation of 0.03 in. or less for the three distances which were measured for the different orientations of the cast.

DISCUSSION

The designed positional accuracy of the laser scanner was assumed to be +/- one digitized sample. This yields an expected range of positional error from 0.03 to 0.05 inches with greater distance from the video camera yielding greater error. The measured error was less than this expected range for 16, within for 10, and greater for only 1 of 29 measurements. The one point out of range was at a radial position far from the camera and at a height more likely to be interior than on a surface profile.

A goal in the design of the laser scanner was to be able to scan subsequent patients incorporating highly specific landmarks so that the scans can be reoriented to a common view for comparison. It was desired that errors associated with rescanning a stump fall within the range anticipated by system design. The observed standard deviation from the samples taken at different turntable positions and different object orientations yielded a standard deviation within this expected range.

CONCLUSIONS

Based on evaluations of positional accuracy and reproducibility of anatomical marking, the laser scanner system is well suited to the task of surface scanning of residual limbs for BKN amputees. Additionally, the system is cost effective and provides 3-D surface profiles in a timely fashion.

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RAPID ANTHROPOMETRY FOR CAD/CAM DESIGN IN PROSTHETICS AND ORTHOTICS

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This paper presents a technical overview of recent advances in integrating three-dimensional measurements gathered with high-speed optical digitizing to CAD/CAM software for orthotics and prosthetics design and manufacture.

CAD/CAM design in prosthetics and orthotics is dependent to a large degree on a fast and accurate method for gathering anthropometric patient data. Until recently measurements were either made by simple hand-held instruments or by motorized tactile probes, both of which place a low limit on the amount of measurements that can be collected over a reasonable period of time. This paper addresses a new means for collecting fast measurements by rapid three-dimensional digitizing with laser triangulation as well as standard methods for interfacing the digitized data with CAD/CAM software.

Rapid three-dimensional digitizers manufactured by Cyberware Laboratory provide 14,000 three-dimensional coordinates per second from patient surface topography. High-speed sensing electronics enable this sampling rate on the face, hands, torso, legs, feet, and other surface contours of the patient. Sample data is gathered from these highly variegated features with the aid of a unique optical path that allows the sensor to receive measurement samples from irregular concave and convex surface topography. Total time for the measurement process varies proportionately with the amount of surface area and resolution required. Sub-millimeter resolution on the craniofacial area normally requires a fifteen-second measurement; millimeter resolution on the transtibial limb area requires half the time, or about eight seconds. Large dorsal surface regions may require longer periods if millimeter resolution is required for the application. As an alternative multiple optical measurement heads may be used to decrease the time required.

In addition to high resolution two other important aids become available to the practitioner, manufacturer, and researcher using CAD/CAM technology with rapid optical digitizing. One is the capability of marking actual patient surface areas with a type of distinguishable feature marker to which the sensor is sensitive. This allows sub-regions to be defined for CAD modeling and eliminates in most instances the need for plaster casts. The second capability provided is real-time graphics. This allows the user to check and alter data graphically on the computer display immediately after the digitizing is complete. The image can be manipulated in three-dimensions by keyboard and mouse commands. Typical commands include rotation, registration marker measurements, surface area measurements, clipping, scaling, mirroring, correlation, statistical data, and format conversion for CAD shaping programs.

To simplify the size and format of large three-dimensional image data files, cylindrical scans are formatted as a table of radii at regular angle and y-axis increments, and for linear scans of regions such as the foot sole, the same format is used with z-values at regular increments. Cylindrical measurements are automatically converted to x,y,z coordinates for computer processing. Output files are converted to CAD/CAM software typically by identifying key delimiters in the file and re-sampling the data to fit the required resolution pitch of the CAD/CAM software. Cyberware Laboratory co-develops this type of interface software with major CAD/CAM software developers. In addition, Cyberware supplies CAD/CAM developer software for researchers and manufacturers interested in developing special standards for graphics modeling or new applications in computer-aided design and manufacturing.

Cyberware Laboratory's rapid measurement technology has been tested in the development of CAD/CAM design of transtibial sockets, hand prostheses and cosmeses, orthopedic and orthotic footwear, custom seating design, craniofacial reconstructive surgery, and surface compensators for therapeutic radiology. The equipment has been thoroughly field-tested and proven in applications as diverse as sculpture reproduction and special apparel design.

Users include large institutions such as New York University Medical Center Institute for Rehabilitation Medicine, Columbia University Bioengineering Institute, the United States Air Force, as well as commercial orthotics manufacturers.

Future improvements of CAD/CAM technology in prosthetics and orthotics will also be helped by this new measurement tool as as the equipment becomes an everyday tool for decentralized clinical locations. Archived patient data will cost little to transport; fitting time and comfort for the patient will be substantially improved. Researchers and manufacturers will be able to make refinements to the technology with easier access to larger volumes of data made with more accurate measurement equipment.

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FUNCTIONAL ACTIVITIES IN SPINAL MUSCULAR ATROPHY PATIENTS AFTER SPINAL FUSION

19.1

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Spinal muscular atrophy patients presents with weakness, greater in the proximal muscles, leading to scoliosis and limited upper extremity function. The purpose of this study is to identify unique aspects of these patients and to understand how spinal fusion affects their function. Forty patients underwent Harrington or Luque rod instrumentation with functional evaluations pre-op and 2 and 5 years post-op. Biomechanical assessment of function is important. Flexibility of the spine is functionally advantageous because distal strength is used to align weaker proximal segments. Post-op, lack of spinal flexibility resulted in a decline in gross motor function and increased use of UE aids due to a change in the trunk position in the weaker patients. The stronger patient's activities were maintained.

INTRODUCTION

Spinal muscular atrophy is an inherited neuromuscular disorder, characterized by generalized weakness secondary to anterior horn cell involvement and occasional involvement of the bulbar nuclei. The patients present with symmetrical muscle weakness, greater proximally than distally . There have been extensive descriptions of the disease entity. In order to categorize the variable presentation of the disease, these patients have been grouped according to age of onset and severity of weakness. All groups except for the minimally involved, eventually develop scoliosis. [3] Their survival into adulthood has become more common. They have normal intelligence and have the potential to lead a productive, fullfilling life. The purpose of this study is to review the characteristics of this group of patients, describe the unique biomechanics they use to function and to understand how spinal fusion affects their activities.

There were 40 patients included with data on preop , 2 year and 5 year postop function seen at Rancho Los Amigos Hospital from 1965 to 1987. Therapy evaluation included mobility, functional activity, and UE equipment use. It is important to understand from the evaluation how the patient is able to perform ADL with muscle weakness or imbalance and ROM limitations. In SMA patients in particular, distal strength is used to manuever their proximal joints. For tasks that require balance, they must maintain their trunk or extremities in the alignment where the weak muscles have the best mechanical advantage and leverage.
Analysis of mobility status revealed that 67% never walked and only 27% walked by age 2. Of the ambulators, 60% were unable to walk by age five. Seventy-seven percent of all patients used manual wheelchairs by age 6, and electric wheelchairs were used exclusively by age 12. At the time of fusion, average age 11.5 years, 95% of the patients were wheelchair dependent and 80% were transfer dependent. Post-op mobility status was unchanged.

Post-operatively gross motor activities were the most affected. Loss of proximal flexibility with an increase in lever arm of the spine eliminated gross motor function for patients with inadequate strength.

Sitting Activities

Similar dynamics occur in the sitting position. A symmetrical pelvis and firm sitting surface provides a stable base to maximize the dynamics between the pelvis and trunk. Distal fixation and strength of both the upper and lower extremities is used to position the trunk. Pre-operatively, the flexible, but still relatively stable trunk is maneuvered forward and back and side to side with assistance from upper extremity and lower extremity muscles. This ability is eliminated when spine deformity progresses to the point of complete spinal collapse.

Post-operatively, the stable but unflexible spine creates a longer lever arm that weaker proximal and distal muscles cannot control. Pre-operatively this may be predictable by evaluating, strength and observing function in relation to body size. It is important to re-evaluate patients post-operatively to determine if strength is adequate to control the trunk. Individual and ongoing assessments are needed as the patient experiences and adapts to the changes in his balance.

UE Function

Upper extremity function is closely related to the ability to maneuver the trunk. Increased reach occurs with forward and side to side trunk lean. Trunk instability requires the upper extremity to be used for support instead of function. Postoperatively the patients that were too weak to control their trunks were positioned against the wheelchair back. The change in position to an upright posture eliminates reach. Patients that do have adequate upper extremity and lower extremity strength, are able to control the increased lever of their trunk and do not need to be supported against the wheelchair back. This group of patients continues to function without the use of equipment, such as mobile arm supports.

CONCLUSION

In conclusion, physical therapy and occupational therapy evaluations of muscle strength, gross and fine motor activities is important in predicting function and equipment needs after spinal fusion. We have observed that wheelchair patients use their strength to balance and function in very individualized ways.

In a disease involving proximal weakness, flexibility of the spine is functionally advantageous. A rigid spine post-operatively creates a long lever arm that weak muscles may not be able to control. In general, gross motor function declined following spinal fusion. The lack of ability to control the trunk in the sitting position post-operatively correlated with the need for upper extremity equipment. Mobile arm supports, lap boards and reachers were needed to maintain function if the degree of muscle weakness required the trunk to be held upright against the chair back.

It has been suggested that long periods of immobilization may be a cause of functional decline. In comparing earlier mobilization in our patients with Luque instrumentation, we found no significant improvement in post-operative function. Disuse atrophy may influence the relationship between levers and muscle strength, but the biomechanical factors are more directly related to the patients function. This biomechanical relationship needs ongoing reassessment by therapists in order to maintain the patient's activity levels. Although there is a compromise of function in some patients, this must be viewed against the predicted functional loss from severe spinal deformity. The benefit of a rigid but stable spine instead of the inevitable unstable trunk segment, allows for functional upper extremity use. Whether or not the patient is strong enough to handle the increased lever arm, the stablized spine frees the arms (with or without the use of equipment) and allows for productive activities into adulthood.

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SEATED LUMBAR/PELVIC ALIGNMENT: A COMPARISON BETWEEN SPINAL CORD INJURED AND NON-INJURED GROUPS

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BACKGROUND

Studies conducted over the past decade have confirmed that the incidence and related costs of pressure sore treatment remain a major health problem. Both clinical and research evidence, although inconcise and inconclusive, are biased towards excessive and/or prolonged application of pressure as being the primary causative factor. More recently, additional contributing factors have been implicated. Some of these factors are: shear stress, impact loading of tissue, elevated temperature and humidity, age, nutritional status, general health, activity level, deformity, body stature, and psychological deficits. It has been proposed that loss of voluntary trunk stability, combined with the imposed configuration of the wheelchair seat, biomechanically necessitates that a person with diminished trunk control assume an abnormal sitting posture. This posture is characterized by a long 'C' shaped kyphotic spine, with an extended cervical spine, a flattened lumbar spine, and a posteriorly tilted pelvis. If lateral trunk deformities are present, trunk imbalance and pelvic deformities in the frontal plane can exist. Finally, it is postulated that this combination of trunk and pelvic abnormalities can be contributing factors to tissue problems (Hobson, 1984; Zackarkow, 1984), the effect of which is not fully understood or appreciated by most researchers and clinicians .

OBJECTIVE

To investigate if abnormal spinal/pelvic alignment(s) can be shown to exist in the SCI population, and what happens to the alignment(s) as a reult of tpyical postural changes in a wheelchair.

METHODS and MATERIALS

Two sample groups of subjects were ramdomly selected: a sample of 10 normal and 12 individuals with spinal cord injury, seven paraplegics and five quadriplegics. An x-ray series including two sagittal views and two frontal views were done on all subjects. Three standard postures were used; neutral midline (P1M), 30° forward trunk flexion (P2) and 15° of right lateral bending (P1R). A body positioning chair (BPC) with the same cushion was used to achieve consistancy of body support and posturing. Each subject was first placed in the upright seated posture (P1M) in the BPC. The BPC was then carefully located relative to the x-ray head and two sagittal views taken, one in the P1M posture and the other in the P2 posture. The P1M posture is defined as the neutral reference posture. The BPC was then rotated 90° and two more x-rays taken in the frontal plane. The first was a repeat of the upright mid-line position (P1M) and the second was in a position of lateral trunk bending to the right (P1R). The modified armrest of the BPC provided a consistent stopping point during lateral trunk bending.

A method modified from the procedures developed by Anderson et al (1979) and During and Goudfrooij (1985) were used to identify and measure the critical variables that define lumbar, sacral, and pelvic alignment in the sagittal plane. The author developed the method for measurement analysis in the frontal plane. In total eight angles and six distances were measured and recorded from each of the twelve disabled and ten normal subjects. It is estimated that an accuracy of ±0.5 cm on distance measurements and ±2° on angular measurements was achieved. Figures 1&2 define the varibles measured.

RESULTS

1) In general, a person with a spinal cord injury (SCI) will sit in their neutral posture with a posteriorly tilted pelvis. On average, the pelvis will be tilted 15° more than non-injured individuals.

2) Forward trunk flexion to 30° causes forward rotation of the pelvis, with angular motion also taking place mainly at the lumbo-sacral joint, SEP-HOR (L5). The mean pelvic angles (L7) change from N=71°, D=56° in the neutral posture to N=79°, D=68° in the flexed posture. Minimal motion takes place at the sacroiliac joint (L6).

3) Sitting in a neutral posture with 100° backrest recline causes the lumbar spine, as defined by spinal segments S1-L3, to assume a lordodic angle of about 26° for people with SCI and about 22° for the able-bodied. The difference of between the groups (4°) was found to be insignificant.

4) The posterior pelvic tilt causes the ischial tuberosities of the person with a SCI to be displaced anteriorly. On average, the ischial tuberosities are displaced 4 cm anterior to those of individuals without a spinal injury.

5) Forward flexion of the trunk to 30° from a neutral upright posture causes the ischial tuberosities to move posteriorly. On average, the posterior displacement is 2.7 cms for individuals with a SCI, and only 1.6 cm for individuals without a spinal injury, an average difference of about 1cm. This small difference tested to be insignificant.

DISCUSSION AND IMPLICATIONS

When sitting mid-line in a wheelchair with a seat to back angle of approximately 100°, the typical posture assumed by individuals with spinal cord injury, as represented by the study sample, on average, will be different from able-bodied individuals. The pelvis will be rotated further posteriorly by about 15°, with the ischial tuberosities displaced further forward by about 4 cm. These findings are in support of the clinical observations reported by Zarkarkow (1984) and Hobson (1984). Surprisingly, the results indicate a slightly larger lordodic angle (S1-L3) in the SCI group (26°) than in the normal group (22°). These values compare favorably with Andersson et al (1979) who reported a total lumbar angle of 25° with backrest inclination of 100°. However, these findings do not support the observations of Lancourt (1981) and Pope (1985) who reported flattening of the lumbar spine in their disabled subjects.

These results suggest that the kyphotic sitting deformity observed in the spinal injured population occurs mainly above the lumbar level, i.e., in the thoracolumbar or thoracic spine with compensation in the cervical spine. This finding has implications as to the height of a dynamic backrest or lumbar pads in wheelchair seats.

A postural change of trunk flexion to 30° causes significant changes to both the angle of the pelvis (P7) and the location of the ischial tuberosities relative to the support surface (X1). The new pelvic angle increases from 71° to 79° in normals and increase from 56° to 68° in spinal injured people; a relative

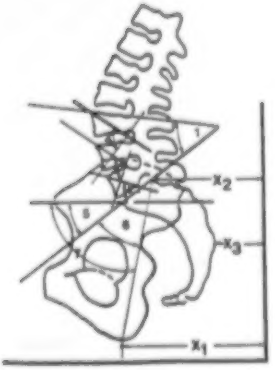

Figure 1. Definition of key angles and distances in sagittal plane: L1 - Lumbar angle; L5 - Lumbosacral angle; L6 - Sacral-pelvic angle; L7 - Pelvic angle (L5 + L6); X2 - IT to reference distance; X2 - Sacral end plate to reference distance

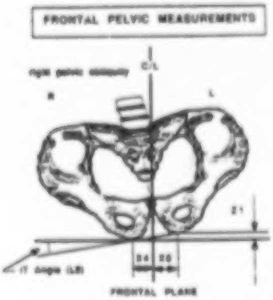

Figure 2. Definitions of key angles and distances in frontal plane: L8 - IT (obliquity) angle, Z1 - Vertical position of IT, X4/X5 - Horizontal position of IT's relative to midline reference.

increase of about 8° versus 12°. Most of the pelvic angle change is due to rotation of the pelvis as measured by the change in the lumbosacral angle (L5). This rotation of the pelvis can cause the ischiae to slide posteriorly about 2.6 cm for paralytic individuals and about 1.6 cm for able bodied individuals.

Forward trunk flexion to 30° is the range that would be typical when a person is actively propelling a wheelchair, working at a desk, or undertaking many manual tasks. Since many individuals conceivably spend considerable periods of time in the flexed trunk positions, pressure profiles and other interface variables should be evaluated in these postures in order to identify conditions of increased risk. These findings have implications regarding the location and size of cushion cut-outs for pressure relief, as well as upon the drawing of conclusions regarding cushion typography from data derived from able-bodied subjects.

The radiographical results also indicate that, on average, individuals with a spinal cord injury will have lateral spinal/pelvic deformities that displace the pelvis laterally from the mid-line. The laterally displaced pelvis will most likely also have a pelvic obliquity angle of about 1.5°. Lateral trunk bending from the neutral posture will have different effects on pelvic displacement. The displacement will be dependent on the direction and magnitude of the pelvic deformity in the frontal plane. Lateral trunk bending of 15° to the right side produces a mean vertical movement of the left ischial tuberosity of about 1.5 cm, with the difference between the two populations being insignificant. Lateral trunk bending of 15° also causes a lateral displacement of the ischiae in the opposite direction, a distance of about 1.5 cm.

The importance of these latter findings is that the location of the pelvis, and in particular the critical bony areas are not static. That is, the bony prominences are constantly moving with every change in sitting posture. Spinal/pelvic deformities are present in varying degrees in the SCI population that can cause an asymmetrical alignment of the pelvis with respect to the seat surface in the frontal plane. Although not studied, a reasonable assumption is that the greater the lateral pelvic deformity (obliquity) the greater will be the asymmetrical distribution of the weight bearing forces. This assumption is consistent with the findings of Drummond, et al (1985) who demonstrated asymmetrical loading of the ischiae in 16 paralytic subjects.

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The Influence of Seat Angle on Metabolic and Perceptual Responses During Recumbent Cycling

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ABSTRACT

The efficacious design of recumbent ergometers and human powered vehicles requires an understanding of the effects of seat angle on human performance and subjective feelings of comfort. This study was done to determine the influence of seat angle on oxygen consumption, expiratory ventilation, heart rate, mechanical efficiency, ratings of perceived exertion, and ratings of perceived comfort. These data suggest that as seat angle becomes more reclined, subjective feelings of comfort increase ($p < .01$). This improvement in comfort seems to occur in the absence of any significant alteration in human performance. Individuals involved in the design of recumbent ergometers or human powered vehicles can make seat angle selection on the basis of comfort and aerodynamic position with the assurance that human performance is not being compromised.

INTRODUCTION

The determination of functional capacity in ataxic individuals is often difficult due to the limitations imposed by compromised balance and coordination. Recently, recumbent bicycle ergometry (RERGO) has been suggested as a valid means to assess the aerobic capacity of ataxic individuals with lower extremity function (1). Also, recumbent human powered vehicles (HPV) offer the possibility of increased mobility and physical activity for persons unable to pedal a standard bicycle. Appropriate design of recumbent ergometers and HPVs requires a knowledge of the effects of seat angle upon metabolic and perceptual responses. This study was done to determine these effects.

METHODS

Six healthy male subjects performed RERGO at work rates of 100, 150, and 200 watts, at a pedal frequency of 80 RPM. Each work rate was performed on a separate visit to the laboratory. During each session, RERGO was performed at seat angles of 90, 105, 120, 135, and 150 degrees presented in a randomized order across all subjects. Each session was separated by a minimum of 48 hours. Subjects began each session with a five minute rest period on the recumbent cycle at the first seat angle, and then performed five minutes of unloaded pedaling. Five minutes of exercise were performed at every seat angle, and subjects were allowed to rest for two minutes between each five minute bout. During the rest period the seat was adjusted to the next angle.

Metabolic variables were measured continuously via a Sensormedics 4400tc Metabolic Cart. Averages, determined from measures taken during the last two minutes of each work period, served as scores for each variable. Data for the following variables were analyzed: oxygen consumption ($\dot{V}O_2$), expired ventilation ($\dot{V}_E$), heart rate (HR), and mechanical efficiency (ME). Ratings of perceived exertion (RPE) were obtained during the last minute of each work period using the Borg 15 point scale. A nine point scale was used to rate the comfort of each seat angle (Figure 1), and these measures were also obtained during the last minute of every exercise period.

RATING OF PERCEIVED COMFORT

1 VERY COMFORTABLE
2
3 COMFORTABLE
4
5 SLIGHTLY COMFORTABLE
6
7 UNCOMFORTABLE
8
9 VERY UNCOMFORTABLE

Figure 1. Nine point scale used for rating the comfort associated with each seat angle.

The recumbent seating apparatus was attached to a standard 10 speed bicycle which was mounted on a Schwinn Velodyne ergometer (Frontline Technologies, Tustin, CA). This ergometer provided a constant work rate, via electromagnetic resistance, which was independent of pedal cadence. The Velodyne has been shown to produce valid and reliable work rates when compared to a standard Monark bicycle ergometer (2). The chain of the 10 speed bicycle was attached to the crank assembly of the recumbent seating device enabling the subject to drive the rear wheel of the 10 speed bicycle mounted on the Velodyne.

The data was analyzed using a two-way ANOVA. Regression analysis was also used to estimate the effect of seat angle and work rate on metabolic and perceptual variables.

RESULTS

During RERGO performed at 100, 150, and 200 watts, seat angle did not significantly effect $\dot{V}O_2$, $\dot{V}_E$, HR, ME, or RPE. Ratings of perceived comfort (COM) were highly related to seat angle ($p < .01$) with 120°, 135°, and 150° being reported as the most comfortable (Figure 2).

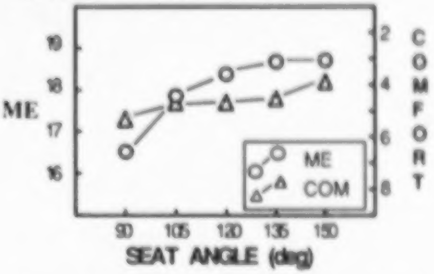

Figure 2. Mechanical Efficiency (ME) and Rating of Perceived Comfort (COM).

DISCUSSION AND CONCLUSIONS

The findings of this study suggest that the mechanical efficiency of RERGO is relatively unaffected by seat angles between 90° and 150°. However, COM seems to increase as the seat angle increases from 90°. It appears that recumbent cycle ergometers can be designed with seat angles that optimize comfort, i.e. angles between 120° and 150°, without augmenting physiological stress. In fact, these data imply a trend toward reduced physiological stress, i.e. a lower $\dot{V}O_2$, $\dot{V}_E$, and HR, and increased ME as seat angle approaches 150° (Figure 2). However, this trend was not statistically significant.

One of the greatest hindrances to the movement of a vehicle through air is frontal drag, which increases as a function of the frontal area of the vehicle. Clearly, the efficiency of an HPV should improve with a reduction in its frontal area. It has been shown that a recumbent position offers a reduced frontal area when compared to upright cycling, and is the position most often used in HPV design (3). From the present data, it is obvious that HPVs incorporating seat angles between 120° and 150°, should benefit from greater aerodynamic efficiency and rider comfort, without compromising the power output of the cyclist. Such an HPV could provide safe and comfortable transportation for elderly and ataxic individuals while optimizing their limited ability to generate power.

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THE USE OF DYNAMIC TILT IN SPACE TO RESOLVE CONFLICTING CLINICAL OBJECTIVES

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ABSTRACT

An evaluation team will often develop goals and objectives for a clients seated positioning which are incompatible, or even mutually exclusive. Dynamic tilt in space is a powerful tool for resolution of competing or conflicting objectives

INTRODUCTION

The authors work together as consultants on an interdiciplinary team developing seating and positioning systems for a primarily school age CP population in the Tallahassee, Florida area. Many of these clients are typically developmentally delayed with severe physical deformities.

The process begins with the IDT developing specific client objectives from a comprehensive client evaluation. Because each professional dicipline has its own unique perspective, the goals arising from them can be very different. Because many of these clients spend the majority of their day in their wheelchairs, the wheelchair becomes the context for resolution of any conflicting objectives. This necessitates the team prioritizing goals, sometimes having to choose between them, not on merit, but on expediency of implimentation in the wheelchair.

Dynamic tilt in space has evolved as a practical way to increase the flexibility of a wheelchair for integrating, not excluding, competing goals and objectives.

BACKGROUND

Therapeutic approach

This model for developing equipment assumes that clients can improve, that no matter how severe the handicap, there is potential for improving physical status and/or acquiring new skills, and that equipment should assist by fostering the clients development in specific areas.[1] Within this model, the equipment becomes an active treatment modality.

Dynamic seating evaluation

Evaluations are dynamic in that the team interacts with clients in the context of an adjustable evaluation chair or simulator.[2] It is in this interface of simulation that the team obtains direct feedback from the client, feedback which allows response to and refinement of presented behavior, with respect to stated goals and objectives.

METHODS

Because this model for developing equipment utilizes a simulator, and because the simulator has included tilt in space as a variable, typically, after setting back to seat angle, seat depth, and seat height, the client is placed in the simulator with a system tilt[3] of 20° to 30°. The reasoning being that it is much easier to establish an optimal pelvis with gravity as an assist. (In fact, this advantage alone often proves important enough to warrant prescribing tilt in the definitive system.)

After adding the remaining needed support surfaces[4] , it is then possible to begin observation of the client. By gradually bringing the client upright against gravity, sometimes degree by degree, it is posible to observe their response to differing orientation by its effect on trunk (proximal) stability, distal function, head control, and respiration.

RESULTS

System tilt has been shown by clinical observation to assist in initial positioning during transfers and repositioning during extended time in the wheelchair. When trunk stability deficits are present, system tilt can augment trunk elongation, and ease respiratory compromise. Also, dependance on straps and other anterior supports is reduced during extended time in the chair, especially during transport by van or bus.

Variable tilt in space, either attendant or client controlled, can vary the clients relationship to gravity, i.e. shift their weight bearing areas, effect respiritory compromise by encouraging postural drainage, and increase comfort. Having the ability to gradually bring the client more upright over time, in the context of augmented support provided by the seating system, allows time for the client to accomodate and begin to integrate distal function, i.e. increase hand and head control.

CONCLUSIONS

Dynamic tilt in space allows choice of the optimal orientation in space for the current activity, and ideally would allow clinically choosing a preset range of tilt available to the care giver. Thus, it would be possible to integrate into the same seating system the apparently conflicting goals for a teenage macrocephallic girl, of acquiring the skill of self-feeding, requiring an upright posture for a relatively short time, and the need to be tilted rearward in the seating system for saftey and stablilty, especially during a two hour bus ride to school.

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A DUAL AXIS POSITIONING IN SPACE SYSTEM TO REDUCE THE EFFECT OF GRAVITY ON SPINAL CURVES

19.5

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ABSTRACT

Individuals who have extensive spinal deformities usually rely on various forms of spinal support such as lateral thorasic supports, TLSO jackets and position in space to control the degree of their condition. Frequently a great amount of discomfort can result from the amount of pressure applied from supports and jackets. This article describes a different approach done utilizing an adjustable lateral tilt in the seating system to reduce the spinal collapsing associated with scoliosis.

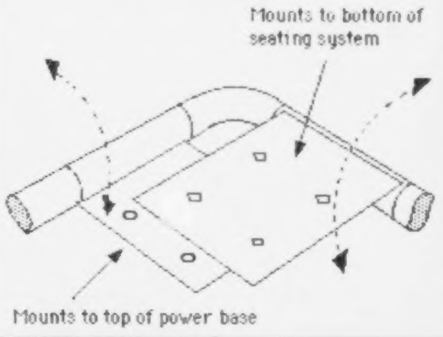
INTRODUCTION AND BACKGROUND

The client described is a twenty-three year old male with muscular dystrophy and a severe scoliotic curve which was shortened on the right side of his trunk. Initially he was wearing a suspension TLSO jacket which was causing him a great deal of axillary pain due to the amount of pressure being applied. Driving his power wheelchair was done with a chin switch, but due to his low seating tolerance he had not used the chair for a period of four months. During the evaluation improved comfort was noted when a three inch platform was placed under the wheels of the right side of the chair (the same side as the shortened side of his spinal curve). This caused him and the wheelchair to sit at an angle tilted to the left and also reduced the effort required to maintain his head in a vertically oriented position. It was then suggested a seating system be designed that would tilt on two planes of motion. The first motion would allow the entire seating system to tilt in space on the anterior / posterior plane. The second motion would allow the system to tilt laterally in the opposite direction of what his trunk was shortening on.

MATERIALS AND METHODS

To accomplish this action, a dual axis hinge was fabricated onto which the seating unit was fastened (shown in figure 1). The power wheelchair base utilized was the client's existing Fortress Scientific 655 which also had a Commander switching interface. Two 24 volt linear actuators (S.K.F. 300mm travel) were attached to provide the necessary movement in both directions. The actuators were driven by a relay interface which was switched via the Fortress Commander interface.

FIG. 1 DUAL AXIS HINGE


Mounts to bottom of seating system
Mounts to top of power base

Drive controls were separated so that forward and reverse were operated by his right and left index fingers while steering was done with his feet. A scan switch was operated by another finger which allowed him to change into the seat tilt mode. In that mode, he is able to control anterior / posterior tilt with his fingers and lateral tilt with his feet. A maximum of 35 degrees is obtainable in lateral tilt, and 45 degrees rearward tilt. The finger switches were incorporated into fiberglass hand splints to ensure consistent placement and stability. The seating system consisted of a planar seat, foam in place back (rigid polyurethane type), swingaway combination trunk support/armrest cradle on right, arm cradle left, swingaway headrest, and foam in place footrest cradle for optimal stability. Client is shown in figure 2.

RESULTS

Upon completion client showed a marked increase in seating tolerance but eventually needed his seat changed to a Roho low profile cushion to releive pain on his left ischial. Minor adjustments were required on the finger switches. Problems were encountered with the Fortress relay box which controlled the linear actuators, but the problem was resolved by adding a current limiting circuit to the system. The client is presently attending college on a full time basis and is capable of spending the majority of his day in the system in a comfortable manner. He drives the chair with a high degree of control and will frequently change his position in space to adjust his posture.

CONCLUSION

This approach appeared to be highly successful in distributing weight and allowing the client to do independent "weight shifts" mechanically. This approach may prove beneficial for those individuals who are not capable of tolerating the lateral pressures applied by other support devices. It is not known to what extent others may adapt to this lateral tilt position and still be as capable of driving since vertical orientation plays a role in spacial awareness. In this case study it provided greater comfort and a chance to be independently mobile in the client's environment.

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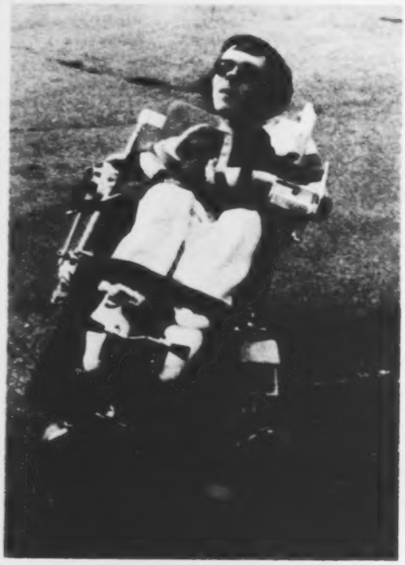

FIG. 2

BACK SURFACE MOTION DURING SEATED VIBRATION

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ABSTRACT

Using a WATSMART, 3-D motion analyzer, the motion of the surface of the human back was assessed during exposure to vertical vibration. Nine sitting subjects were vertically shaken at discrete frequencies from 3 to 10 Hz. Motion data from discrete points on the back were ensemble averaged. Results showed a major natural frequency occurs near 4 Hz and large amplitude motion at the PSIS from 6-10 Hz.

INTRODUCTION

The objective of this study was to quantify the motion characteristics of the surface of seated subjects' backs in response to seated vertical vibration using the WATSMART infrared-based motion analysis system. This technique provided a means of measuring the displacement transmissibility relationships between different parts of the back as the vibration shock wave propagated up the back. Even with errors due to skin motion, the qualitative description of the relative motion remains useful.

BACKGROUND

Determining the natural frequency of the seated individual in a vibration environment is an important step in seat design to prevent vehicle operation related low back pain. Previous workers have studied back response via EMG (4,5), pins placed transcutaneously into vertebral spinous processes (1,2) and limited back surface motion (2,3).

MATERIALS AND METHODS

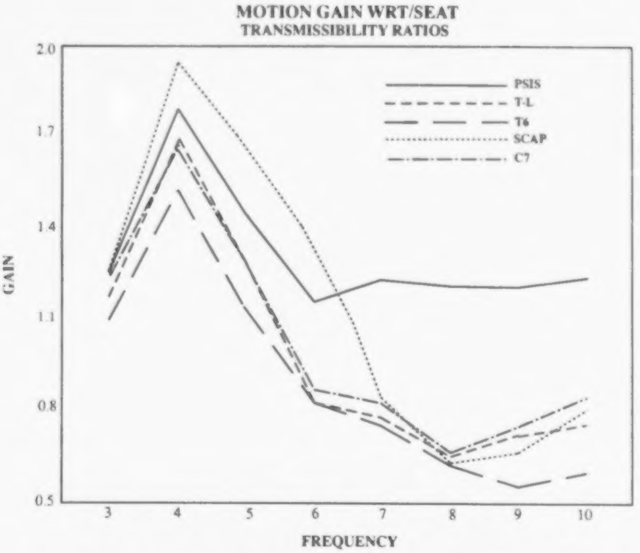
9 people were studied for their response to seated vertical vibrations produced by a servo-hydraulic vibration simulator at discrete frequencies from 3 to 10 Hz and accelerations of 0.1 g(rms). They were instructed to maintain a seated, relaxed posture with feet supported. 8 (3-point) infrared-emitting diodes (IREDs) were attached to specific points of the seat and back of the subject (seat pan, left and right PSIS, thoraco-lumbar junction, T6, left and right scapulae, and C7). Two cameras, (each containing photodiode arrays sensitive to infrared), monitored the seat and back surface movement for a duration of 2 seconds by detecting the two-dimensional position of each IRED and converting them into three-dimensional coordinates. For each point and each vibration frequency used vertical displacement components were smoothed in time. They were then ensemble averaged over two complete periods. The ensemble averaging allowed random errors to be averaged out. Using the peak-to-peak displacements of each point and that of the seat pan as the reference, the transmissibility (motion of the point of interest divided by the motion of the seat) for each point on the back was calculated at each of the vibration frequencies.

RESULTS

At a 3 Hz vibration, there was no relative motion between the seat pan and other points on the body. The entire seat-body system was moving as a rigid mass. All regions exhibited the greatest relative motion (with respect to the seat) at 4 Hz. As the frequency increased above 4 Hz, all points moved less. However at frequencies above 6 Hz, the PSIS points continued to move about 25% more than the seat did. Thus, there was relative motion between the PSIS and the points above that. The greatest relative motion existed between the PSIS and the thoraco-lumbar junction. A potential limitation of this method must be kept in mind. There may be an effect of the compliant skin between the skeleton and the IRED. Although the IRED-skin construct natural frequency was not assessed, its effect should have been minimized by 1) the ensemble averaging performed and 2) the fact that relative and not absolute motion was assessed.

DISCUSSION

This is a provocative addition to previous seated vibration studies. Usually, the transmissibility of acceleration to the head peaks between 4.5 and 5.5 Hz. Above 5.5 Hz, the output acceleration transmissibility decreases to an amount less than the input. This study observed that displacement transmissibility (and by inference: acceleration) to the PSIS



Ratio of motion of points on the back (mid-PSIS, thoraco-lumbar junction, T6, mid-scapula, and C7) to motion of the seat during 3 to 10 Hz vibration.

remains greater than 1.0 at vibrations above 6 Hz. The displacement transmissibility of the thoraco-lumbar junction however, exhibits less than 1.0 above 6 Hz. Hence at all frequencies above the natural frequency (up to 10 Hz), there is large relative motion between the PSIS and the thoraco-lumbar junction. It is very likely that the pelvis is rocking and the lumbar region is experiencing repetitive mid sagittal plane bending. Previous work (1,2) predicted maximum motion within the lumbar region at the seated natural frequency. This work confirms it but also shows large relative intralumbar motion at frequencies above resonance. This is further evidence that shock and vibrations above the seated natural frequency pose risks to the seated driver.

CONCLUSIONS

A protocol has been developed for analyzing back surface motion in sinusoidal vertical vibration environments. Increased motion at the natural frequency of the system was observed at 4 Hertz. Large motion was seen over the PSIS at and above 6 Hz.

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CLINICAL EXPERIENCES IN WOUND HEALING BY ELECTRICAL STIMULATION IN SCI PATIENTS

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ABSTRACT

The present paper deals with clinical experiences in the application of electrical stimulation (ES) in the healing of wounds in spinal cord injured (SCI) patients. The analytical results referring to healing 21 wounds in 18 SCI patients show that out of seven wounds included in the control group only one healed, whereas the remaining six were subject to stimulation after a period of one month. In the course of stimulation all wounds healed.

INTRODUCTION

Following the example of other institutions in the world, the University Rehabilitation Institute dedicates much effort to the healing of decubitus ulcers representing one of the numerous complications experienced by SCI patients. On the basis of the results obtained in a two-year study on wound healing by means of ES (1985-1987) we decided to proceed with research in this domain. Thus, a new three-year investigation project has been initiated, which will include a larger number of patients. In the first phase stress will be laid above all on obtaining quantitative and statistic results in comparison with control groups.

METHODS

The patients are divided into two groups. In the first ES of wounds is introduced immediately, while the second i.e. one-month control group consists of patients chosen by random principle. If after four week the wounds of the control group fail to heal, ES is introduced. In the control group a longer period of observation would be most desirable, however, it is impracticable due to ethical and financial reasons.

Stimulation is performed by means of a miniature one-channel stimulator D-5, produced by The Jožef Stefan Institute in Ljubljana. The stimulator is commercially available and can be prescribed by a specialist, which substantially reduces the costs of treatment. Stimulation takes the form of biphasic impulses of an amplitude of up to 50 mA, frequency of 40 Hz, and impulse width of 0.25 ms. Amplitude is adjusted to an almost imperceptible muscle contraction. A stimulation cycle lasts 4 s followed by a 4 s pause. The original stimulation time was prolonged from 30 to 60 minutes twice a day. In this way the patient still has time to participate in the regular rehabilitation programs. Applied are two flexible self-adhering Pals plus[1] electrodes of 4x5 cm.

Records are kept both on patients subject to stimulation and those from the control group. They cover personal data, cause and level of the lesion involved, duration of affection, time of wound occurrence, and data on other investigations connected with the healing of the wound. Taken down in the records is the following information: daily activities of the patient in programs of physical and occupational therapy, time spent sitting in the wheelchair, time spent lying on the bed. It is important that the patient should take an active part in sporting activities, since the tendency to the occurrence of decubitus ulcers is much less expressed in active sportsmen. In the course of performing ES of wounds, FES is suspended not to harm the objectivity of the study as in our belief FES might have favourable "side effects" on the healing of wounds (2).

We begin by determining the largeness, depth and volume of the wound, calculate its superficies in square centimeters, and take a photo of the wound. This procedure is repeated once a week. The depth is measured by means of a sterile surgical ligature-holding forceps introduced into the wound and eventual pockets. The volume is determined by the quantity of sterile physiological solution with which the wound is filled up to the epidermis brim. In this procedure a sterile laboratory pipette is applied.

Throughout this period the stimulated and the control patients enjoy the same standard nursing including regular turning over of the patients in the bed, as well as dressing and cleaning of wounds once or, if necessary, twice a day, by using a 1% solution of Cetavlon[2], H_2O_2

or 3% SAB (boric acid solution). In the case of deep and festering wounds a gentamicin ointment (Garamycin[3]) or 1% sulfadiazine (Dermazin[4]) is applied.

RESULTS

In a group of 18 patients having totally 21 wounds the results as obtained were analysed from a statistic point of view (3). On the basis of a random sample seven patients were placed into the control group for a period of four weeks, whereas in the others the ES of wounds was started right away. Of the seven wounds in the control group only one smaller shallower wound of 3.2 cm^2 healed without ES. After four weeks the other wounds are subject to stimulation. In five cases the wounds are stimulated by alternating current, whereas one wound, included in another study, by direct current. After the application of ES all wounds healed.

DISCUSSION

Beside a quantitative statement of the effects of ES on the healing of wounds the object of our studies are also mechanisms of healing entering into this process. By applying a temperature display system TOPSCAN 808[5] changes in the body temperature on the skin surface were studied at a simultaneous application of ES in the patients participating in the investigations and healthy volunteers. The measurements were performed in a special room with a constant ambient temperature and low humidity. The individuals to be examined were prepared 30 minutes prior to the beginning of the measurements whereat all those bodily parts to be subject to ES were uncovered. It was found that in the SCI patients the surface body temperature of the stimulated area increased by several degrees Celsius already in a short time, whereas in the healthy volunteers no noticeable increase in temperature could be stated on the skin surface. This leads us to conclude that in SCI patients ES improves blood circulation in the vicinity of the wound subject to stimulation, which promotes a quicker healing.

We have tried to study wound healing mechanisms also by means of biopsy with a histologic analysis of the affected tissue, enzymatic tests, oxymetry, scintigraphy of microcirculation in the vicinity of the wound, and bacteriological analyses. At present these methods are still going through an experimental phase, so they are as yet unsupportted by scientific analyses.

CONCLUSION

As a result of long-year experiences acquired in treating decubitus ulcers by means of ES we believe that the method is successful, less expensive than the surgical treatment and quite safe for the patient at a relatively simple application. However, not all of the mechanisms entering into this process have been thoroughly elucidated so our future research is to be directed to this objective.

ACKNOWLEDGEMENTS

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TOWARD A LOGIC FOR THE EFFECT OF ELECTRICAL STIMULATION ON WOUND HEALING

21.2

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ABSTRACT

The purpose of this study is to find out the relation between the duration of wound healing and type of treatment, i.e. classical versus treatment by electrical stimulation (ES). The healing of the wounds is described by decision rules using the Assistant inductive learning system. The decision tree is generated on the basis of data collected from 28 wound healing cases (7 treated by conventional treatment and 21 by ES), each described by 9 parameters. The time constant is calculated from the time course of the wound area and depth and is used to define the effectiveness of healing process. From the obtained decision tree it is clear that ES significantly enhances wound healing.

INTRODUCTION

Essential biological functions such as cellular growth are controlled by weak, self-induced (endogenous) electromagnetic fields (1,2). It is now well established that these functions can be modified also by means of external fields. We report about the effects of such exogenous electrical fields on wound healing, a process of considerable fundamental and clinical interest.

METHODS

Time constant of wound healing

A study was performed on SCI patients with wounds on the sacrum or trohanters. The electrical stimulation program was described in our previous work (3) while clinical experiences can be found elsewhere (4). Wound area and depth were measured once weekly and taken as a descriptors of the healing process. It was found that the wound area plotted on a time scale behaves according to the exponential function. We tested the possibility of the healing process being described by the equation

$$S = S_0 \, e^{-\frac{t}{\mathcal{T}}},$$

where S_0 is the initial wound area (at the begining of controled conventional treatment or treatment with ES, S the area at time t and $\mathcal{T}$ the time constant of the healing process. In order to facilitate the determination of time constants a logarithmic plot was introduced. With $S = e^X$ and $S_0 = e^{X_0}$ we obtain

$$X = X_0 - \frac{t}{\mathcal{T}} \quad \text{and} \quad \mathcal{T} = \frac{t}{\ln (S_0/S)}$$

Data and estimation methods

Data including level of injury, patient's age, duration of disability (months), wound location, duration of wound before control or stimulation (weeks), initial wound surface (cm^2) and depth (mm) were collected for 7 wounds treated by classical treatment and 21 wounds treated by ES. It is the purpose of this report to find out the relations between the inherent parameters and time constant of wound area determined either by classical treatment or by ES.

As we had data for only 28 wounds the estimation of electrical stimulation effects can not be done reliably although the effect is obvious. Instead of statistical estimation we selected a symbolic approach. We wanted to describe the healing of the wounds with decision rules using the Assistant inductive learning system.

Assistant (5) generates a decision tree from known examples of solved decision problems. A decision tree can be viewed as a symbolic description of relations in a given problem. Furthermore the position of a certain parameter in a decision tree indicates its importance for the decision problem. The root of the tree represents the most important parameter to the given decision problem (5).

We posed the decision problem as prognosing the value of the time constant from collected and measured data related to the wounds. The decision classes were selected as intervals of the time constant (Table 1). Assistant generated a decision tree on the basis of data collected from 28 wound healing cases (each one described by 9 parameters).

RESULTS AND CONCLUSIONS

The number of wounds treated by electrical stimulation (yes) and clasical treatment (no) belonging to a particular decision class is presented in Table 1.

ES	≤ 1	$1 \cdots 2$	$2 \cdots 4$	$4 \cdots 10$	> 10
yes	3	7	7	4	0
no	0	0	2	2	3

Table 1. Five classes obtained by dividing te healing time constant $\mathcal{T}$ (weeks) into intervals. The number of stimulated and unstimulated wounds for every class is presented.

Fig. 1 presents the obtained decision tree (for brevity in leaves only the most probable classes are displayed). The most important parameter is wound depth which warns that basing the time constant only on changes in wound area does not define the healing process completely. It also appears that wounds not deeper than 0.5 cm heal significantly faster when treated with electrical stimulation than those treated with classical treatment. The prognosed time constant for nonstimulated wounds is > 10 weeks. Time constants of wounds treated by ES depend on initial wound area i.e. if wounds are less than 1 cm^2 then $\mathcal{T} \leq 1$ and if wounds are greater then 1 cm^2 then $1 < \mathcal{T} < 4$. It also appears that the healing of wounds deeper than 0.5 cm depends on te duration of the patient's disability. The physicians agreed that the importance of the duration of the disability stems from the patients experience in self-care.

From the obtained decision tree it is evident that time constant must contain also the information about depth. We decided to calculate an additional time constant

$$\mathcal{T}_{depth} = \frac{t}{\ln (d_0/d)}.$$

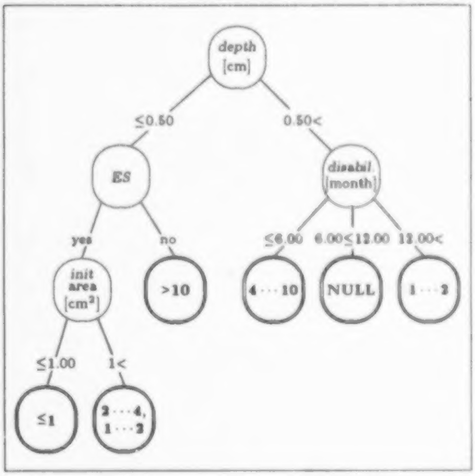

Fig. 1. The decision tree generated by Assistant for the time constant which contains the information cocerning wound area only.

The new time constant is defined as the sum:

$$\mathcal{T} = \mathcal{T}_{area} + \mathcal{T}_{depth}.$$

According to the values of the new time constant we redefined also the intervals for classes. The new decision tree is presented in Fig. 2. The ES appears as the most important parameter in the healing process. It is important to note that the longest time constants are associated with the wounds not treated by ES. Again, the time constants for ES healing strongly depend on the initial depth and area of the wound. Though limited, the available set of clinical data imposes a clear conclusion that wounds treated by ES will heal significantly faster than wounds approached only with conventional treatment.

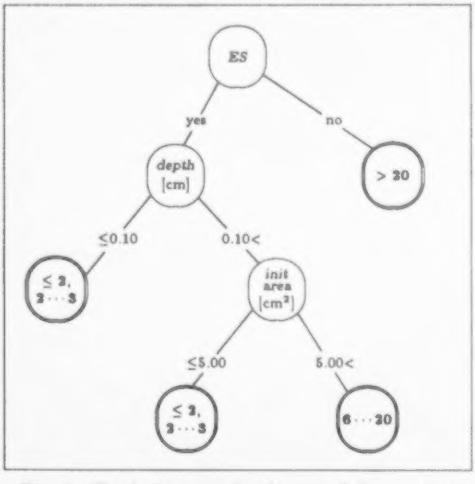

Fig. 2. The decision tree for the sum of the constants: $\mathcal{T} = \mathcal{T}_{area} + \mathcal{T}_{depth}$.

EPILOGUE

We showed that advanced tools like Assistant can help us in producing a clear and simple description of phenomenon that ES achieves a significant enhancement of wound healing. The next challenging step is searching for a rational explanation of healing mechanisms.

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BONE BENDING PROFILES IN STANDING

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ABSTRACT

We are presenting the bending moment profiles in lower extremity long bones of normal and SCI subjects while standing by means of FES. The distribution of the gravitational or "row" bending moment over the bone length is calculated and presented together with the indirectly determined bending moments resulting from muscle activity.

INTRODUCTION

The locomotor functions and the associated movements such as standing up, standing, walking and sitting down are important activities of daily life. Many different activities are performed while standing. The standing posture is vital for proper functioning of many internal organs and a prerequisite for walking (1,2,3). Standing is an elementary function which is first experienced by SCI patients in Functional Electrical Stimulation (FES) locomotion restoration program (4,5). To highlite the importance of biomechanical aspects of FES assisted standing in SCI subjects the bending profiles in the long bones of normal subjects and completely paralyzed SCI subjects have been analyzed. It is, namely, very important not to overstres the tubular long bones and joint structures while performing various FES enabled functions. For the long bones the bending loading is critical. The contribution presents the measuring results of bending loading to long bones of lower extremities in normals and paraplegic subjects using FES while standing. Is is also demonstrated muscle action contributes not only to joint locking, but primarily to bending loading reduction.

MATERIALS AND METHODS

Twenty normal subjects with no known neurological or orthopedic problems, five of them female and fifteen male, were chosen to participate in the study. Average age was 32.6 years, average height 171 cm and average body weight 72.7 kg. In addition six completely paralyzed SCI male subjects were randomly selected (Table 1). All of them have successfully completed the FES restrengthening program of the atrophied paralyzed knee extensors. They were, however, not equally successful in performing FES assisted standing. Nevertheless, they were all able to stand by help of stimulated knee extensors for at least 10 minutes. Normal subjects performed the following movements: standing up from a chair, standing for few seconds and sitting down. Styrofoam blocks were used for seat height adjustment. A backrest was used to standardize the sitting posture. The subject was asked to cross the arms in front of the chest. Twelve repeated measurements of standing up and sitting down were assessed. Patient were measured while standing in bars with left leg loading the force plate. They used arms for balance only.

TABLE 1

Sub.No.	Age	SCI level	Time past injury	Accident	FES training
1	20	T11	11m	fall	9m
2	50	T5	3y 3m	GSW	5m
3	46	C6	4y 5m	fall	1y
4	26	T8	5y 5m	MVA	1y 5m
5	20	T5	1y 7m	MVA	1y 6m
6	26	T5,6	2y 5m	MVA	2y

Force plate based on strain gauge transducers (AMTI model OR6-5-1) was used to record ground reaction forces (F_x, F_y, F_z) and corresponding orthogonal moments (M_x, M_y, M_z). Black and white markers were placed on the body landmarks at the ankle, knee, hip and shoulder for photographic position assessment. An IBM PC XT computer was used to collect data in real time, with 16 channel 12 bit A/D board (Tecmar Labmaster). The data collected were processed by universal waveform analyzer (Data Precision DATA6000) and further evaluated by the IBM PC AT MATLAB program (The Math Works Inc.)

The segment mass, it's center of mass and corresponding specific densities were calculated using the ratios given by Winter (7). The bending moment profiles were assessed through the force plate measurements and still photography. The z axis is perpendicular to the force plate and z=0 was on the plate surface. The x axis (y=0) was placed at the subjects ankle joint. According to the coordinate system proposed the bending moment moment M_{xi} in the point (y_i, z_i) of the sagital plane was calculated by the help of the following formula $M_{xi} = M_{rest} + M_{part\ i} + F_y z_i$. Here, (y_i, z_i) was the point on the straight line passing from ankle to knee and to hip joint. M_{rest} represents the upper mass moment. In the thigh this is a moment belonging to the mass of the trunk while in the shank the mass of the thigh was added. $M_{part\ i}$ is produced by the upper part of i^{th} segment which was placed higher than the point z_i and not included in M_{rest}.

RESULTS AND DISCUSSION

The gravitational bending moments (M_g) for two normal subjects are presented in Fig. 1. The most often used standing postures are shown. Kinematic data were averaged over the whole quiet standing phase. It is interesting to note that almost the same posture is used also in patients (Fig. 2). The bending moment profiles resulting from gravitational force can have trapezoidal or some kind of triangular shape. It is further interesting observation that the lowest torque values

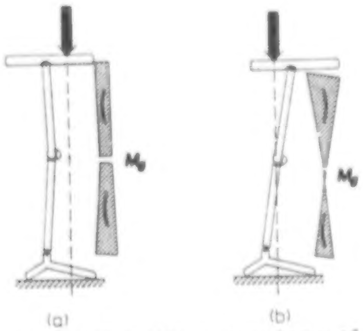

Fig.1 M_g bending moment in long bones of lower extremities of a healthy subject.

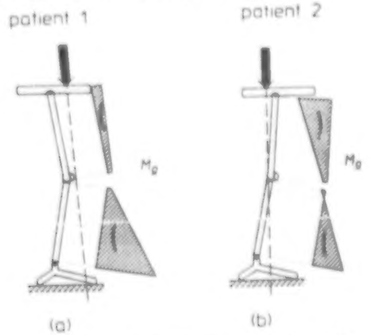

Fig.2 M_g bending moment of a paraplegic.

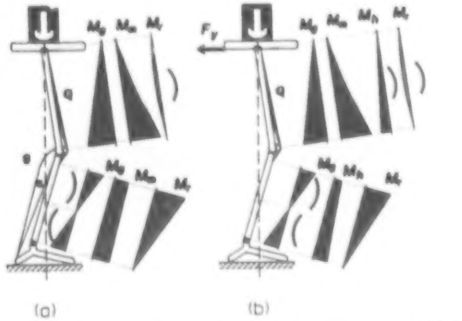

Fig. 3 Bending moments profiles in healthy (3a) and paraplegic (3b) subject.

occur in the knee joints for arbitrarily selected standing postures.

To validate the importance of the results presented, a simple hypothetical model is shown in Fig. 3. To facilitate further reasoning the body weight is directed through hip joint. Here the M_g moment caused by the gravitational force is shown together with the bending moments caused by muscles M_m and the resultanting bending moment M_r. The M_r is effectively stressing the bones.It is evident that it's quantitative distribution over the bones is highly dependent on the muscle force and attachment points. Consider Fig. 3a, where quadriceps (q), soleus (s) and gastrocnemigous (g) muscle are active. The femoral bone is not under heigh stress, while the proximal section of the tibia is considerably stresed (triangular shape).In paraplegic patients standing static equilibrium is maintained by the forces exerted by the hands. FES activates usually only knee extensor muscles. F_y in Fig. 3b represents the force produced by hand support while M_h is bending moment provoked F_y. The force F_y compensates for the missing muscle activation below the knee and causes that person is statically balanced, thus $\sum M_j$ = 0 at the joints. Observing Figures 1,2 and 3 we can conclude that "row" gravitational bending moments are similar in healthy and paraplegic persons. The main difference is in the way of compensating of those moments.In normals the gravitational bending moments are compensated by activation of various muscles. Only small number of muscles is FES activated in paraplegic patient subjects. Here, additional compensation results from the hand support.The resulting bending moments are again similar in both groups.

CONCLUSIONS

The results presented should be considered as an approximation of the in reality bending moments occurring in the long bones during quiet standing. The results obtained in normals and paraplegic patients standing by means of FES indicate that in both groups the bending stressing is similar. According to our observation it can be concluded that FES standing of paraplegic patient is very close to the standing of normal man and therefore it is very unlikely that secundar pathologies in joint and long bone fractures may be occur.

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Inhibition of Soleus Muscle Stretch Reflexes Through Antagonist Electrical Stimulation in Normal Subjects and Subjects with Spasticity

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ABSTRACT

The potential of using electrical stimulation to inhibit the stretch reflex in normal subjects and subjects with spasticity was investigated. Electrical stimulation was applied to the antagonist muscle just prior to a perturbation to induce the stretch reflex of the agonist muscle. It was found that this inhibits the stretch reflex in normal subjects and can inhibit the hyperactive stretch reflex in some subjects with spasticity.

INTRODUCTION

One of the most important neural mechanisms in the control of muscles is considered to be the monosynaptic reflex arc. This reflex has been extensively studied by many researchers. Theories for its role in normal muscular control mechanisms range from length regulation to load compensation and velocity regulation(1). Nevertheless, the presence of an exaggerated stretch reflex is the primary indicator for a neurological disorder such as cerebral palsy, multiple sclerosis or Parkinson's disease(2). Traditional methods of spasticity management include therapy, drugs and surgery. All of these methods are limited in the degree to which they can reduce the effects of spasticity.

This paper describes the effects of electrically stimulating the tibialis anterior muscle on the stretch reflex of the soleus muscle in normal subjects and subjects with spasticity. It was found that electrical stimulation applied to the tibialis anterior muscle just prior to a mechanical disturbance that invokes the stretch reflex in the soleus muscle inhibits the stretch reflex of the soleus muscle in normal subjects and can inhibit the hyperactive stretch reflex in some subjects with spasticity.

EXPERIMENTAL SETUP

A block diagram of the experimental setup used is shown in Figure 1. A PDP11-34 computer controls the entire system and performs the experiments as well as all data acquisition. The subject's foot is rigidly strapped to a DC motor-driven cradle which can impose controllable disturbances about the subject's ankle. Electromyographic (EMG) activity in the soleus muscle is monitored through surface electrodes and stored in the memory of the computer at the rate of 400 Hz. The computer also controls an electrical stimulator which delivers a stimulus burst of desired duration at a specified time during the trial. Stimulus frequency is fixed at 55 Hz.

EXPERIMENTAL METHODS

Experiments were performed on six healthy subjects and six subjects with spasticity in the soleus muscle. Each subject was comfortably seated and the foot was rigidly strapped to the rotating cradle of the Ankle Actuating Device (AAD). Surface EMG electrodes were placed longitudinally over the soleus muscle just below the gastrocnemius muscle belly. Surface stimulation was applied through the controllable stimulator to deliver a single pulse to the peronneal nerve just large enough to cause a twitch in the tibialis anterior muscle but not the peronneal muscles. The computer was then programmed to impose a sudden movement about the ankle joint causing a dorsiflexion of the foot (stretching the soleus muscle) from the neutral position to 20 degrees of dorsiflexion with a maximum velocity of 180 degrees per second. This range was adjusted for those subjects with contractures in order to keep within their comfortable range of motion. Typically, this perturbation caused a stretch reflex to be measured from the soleus muscle at approximately 100 milliseconds after the onset of the disturbance.

Two types of experiments were then performed for each subject:

Exploratory Experiment: A fixed stimulus amplitude and a stimulus burst consisting of four 300 microsec. pulses 16 msec. apart was used. The stretch reflex of the soleus muscle was examined when the latency between the electrical stimulus and the mechanical disturbance was varied from 20 msec. to 300 msec. in steps of 20 msec. For each new latency, the trial was repeated five times.

Comparative Experiment: From the observations of the exploratory experiment, the latency at which the stimulus was most effective in inhibiting the stretch reflex of the soleus muscle was determined. The experiments were then repeated thirty times without stimulation, followed by thirty times with stimulation at the latency described above, and then thirty times again with no stimulation.

RESULTS

The experiments described above were performed on six normal subjects and six subjects with spasticity resulting from three neurophysiological disorders. For all the experiments, the stretch reflex EMG was quantified by integrating the rectified EMG signal from 50 msec. to 150 msec. after the onset of the ramp disturbance(3). The results obtained were as follows:

Normal Subjects: Figure 2 shows the typical results obtained from a normal subject during the exploratory experiment. The graph is for the integrated stretch reflex EMG averaged over five trials and normalized to the maximum level plus one standard deviation. It is clear that at a latency of approxiomately 160 msec. the electrical stimulus considerably inhibits the stretch reflex of the soleus muscle. For all six subjects the latency was consistently in the same range. The results from the comparative experiment showed levels of inhibition ranging from 50% to 86%. Paired t-test showed high levels of significance (p<.001) for all subjects.

Subjects with spasticity: Two subjects with cerebral palsy, two subjects with multiple sclerosis and two subjects with a spinal cord injury were also examined. Inhibition ranged from 20% to 76% with the highest inhibition observed in the two subjects with multiple sclerosis and one of the subjects with cerebral palsy (P<.001). The latency of the inhibitory effect was 130 msec. on the average. One subject with cerebral palsy did not display any inhibition on both sides, while one of the subjects with a spinal cord injury displayed no inhibition on the right side. Figure 3 shows the stretch reflex from one of the subjects with cerebral palsy when no stimulation was applied (top traces) and with stimulation (lower traces) for both left and right sides. Note the clonus in this subject which manifests itself as the secondary burst of activity in the top traces. Stimulation was also effective in reducing the first burst of activity as well as the clonus.

CONCLUSIONS

It was shown that stretch reflexes may be inhibited using electrical stimulation in normal subjects and subjects with spasticity. The long latency in the response indicates that the observed phenomenon may be mediated through post-synaptic mechanisms. Future investigations will be directed towards the exploration of this phenomenon in gait.

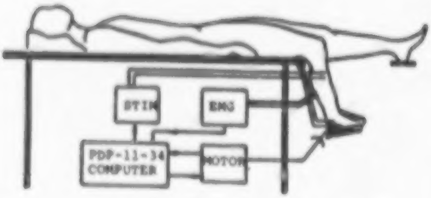

Figure 1: Block diagram of experimental setup.

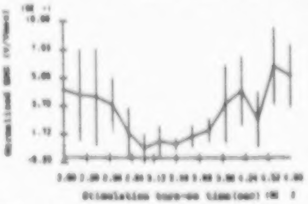

Figure 2: Typical results from exploratory experiment on a normal subject.

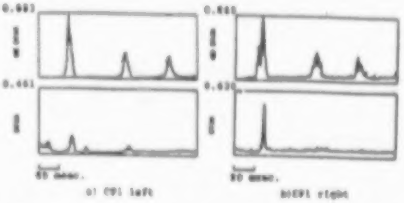

Figure 3: Inhibition of stretch reflex in a subject with spasticity.

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FORCE-CURRENT MEASUREMENT SYSTEM FOR EVALUATING MUSCLE PERFORMANCE DURING FUNCTIONAL NEUROMUSCULAR STIMULATION

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ABSTRACT

A force-current measurement system was developed to evaluate, via a microcomputer, the current intensity vs isometric force output during functional neuromuscular stimulation (FNS) of paralyzed quadriceps muscles. Force output, as detected by a strain-gauge transducer at the ankle level, can be plotted as a function of current during repetitive ramped-increases and -decreases (linear; 0-150 mA/18 sec) of stimulation intensity. Preliminary results indicate that as the muscles go from their fresh, rested state toward fatigue with repetitive contractions, the current threshold for contraction tends to increase; the force-current loop undergoes a progressive widening with respect to the ramped-increase and -decrease; and the force per unit current (slope) and the maximal force output tend to decrease. These variables seem to be useful indices of muscle performance during FNS. They might also provide vital information for the design of accurate closed-loop control systems for prolonged and effective FNS-assisted activities by individuals with paralysis.

INTRODUCTION

FNS of paralyzed muscles is being studied in research laboratories and applied clinically with the goals of improving the health, physical fitness and rehabilitation potential of individuals with various neuromuscular disorders. Common uses of FNS include exercise training and assisting skilled activities. Successful FNS use requires a high degree of muscle control and force generating capability (strength and endurance). Considering the heterogeneous muscle performance capability that exists among the many potential FNS users, and the fact that muscle performance can change with approaching fatigue, exercise training and numerous other conditions, stimulation current requirements tend to be quite individualized and will change during prolonged activities. In addition, the development of closed-loop, feedback systems for accurate muscle control [1-3] during FNS requires detailed muscle force/stimulation current information. Thus, some means of objectively evaluating the relationship between muscle force and stimulation current during repetitive contractions of ramped intensities appears to be desirable. However, there have been no standardized systems or techniques described to provide these data in a valid and reliable manner.

Therefore, the purpose of this paper is to describe a system and techniques to objectively evaluate FNS muscle performance via force-current loop data during repeated contractions of ramped intensities. This system provides information concerning the: 1- stimulation current threshold for contraction; 2- contraction force per unit of stimulation current; 3- contraction force achieved at maximal stimulation current; 4- smoothness of the contraction; and, 5- muscle fatigability during repetitive contractions. It was decided to initially study the quadriceps muscles during FNS-induced isometric contractions.

METHOD

Instrumentation. Figure 1 illustrates the experimental setup comprised of: an exercise chair with adjustable vertical and horizontal leg positioning to maintain a constant knee joint angle; an isometric force sensor at the ankle level with continuous position adjustment to be certain that the force on the calf is normal to the force sensor; a device placed over the calf to distribute the generated force over a large surface area (thus minimizing the risk of accidental bone fracture at high force output) without affecting the force sensor reading; a constant current stimulator (STIM) with ramped output intensity; surface electrodes placed over motor points of the quadriceps muscles; a signal conditioning system (SIGNAL COND) to minimize artifacts; and a computer for data acquisition.

As shown in Figure 1, the output from the stimulator (biphasic pulses of 0.3 msec in duration at a frequency of 35 Hz) provides the stimulating current to the subject's muscles, while a secondary signal indicative of this current is fed into an analog-to-digital converter (ADC) in a microcomputer (through a signal conditioning unit). Information from the force sensor is also fed into the ADC through the signal conditioning unit. A computer program is used to sample the force-current data continuously during the ramped increases and decreases in stimulation current.

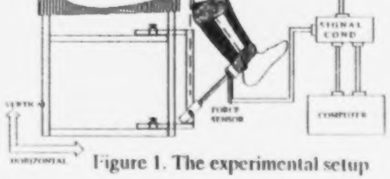

Figure 1. The experimental setup

Protocol. To operate this system, the strain-gauge force sensor is first calibrated with known weights. Bipolar surface electrodes are then placed over the subject's right or left quadriceps muscles, and the chair and force transducer mounting assembly are adjusted for the proper knee joint position. A stimulation cycle consists of a linear ramped increase in current from 0 to 150 mA max over an 18-sec period, followed by an identical ramped decrease in current. A testing session typically consists of as many as 40 stimulation cycles separated by 4-sec rest intervals. Either the stimulation intensity is permitted to proceed to full output of 150 mA regardless of force output, or maximal force output is limited to what is considered to be a safe value (at a lower than max stimulation current). The session is discontinued when muscle fatigue occurs.

RESULTS AND DISCUSSION

Figure 2 illustrates the relationship between stimulation current and force output for the paralyzed quadriceps muscles of a male spinal cord injured subject. The five contractions shown were samples of the 33 contraction session (every 8 contractions). Maximal force output was limited to 100 N. When the muscles were rested, the initial contraction threshold was about 50 mA. However, as fatigue was approached, contraction threshold progressively rose and was almost 80 mA for the 33rd contraction. The rise in contraction threshold had been previously reported in [4]. This increase may be due to the fatiguing of the more superficial muscle fibers, and the recruitment of deeper muscle fibers whose motor neurons have a smaller diameter and a higher threshold level [5].

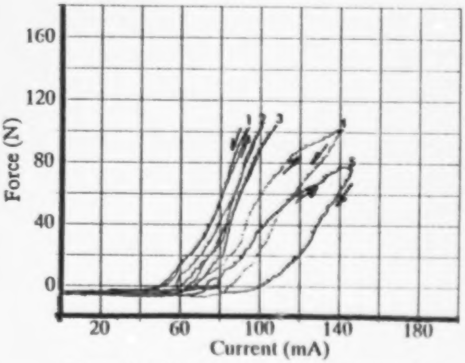

Figure 2. Plot of force - current relationship

It was also observed that the slope of the force-current relationship tended to decrease as fatigue was approached, and the muscle eventually was unable to achieve the target force output. Figure 3 illustrates the relationship between force output per unit of current during the repetitive contractions. In general, there was a progressive decrease in contraction force per given current levels (i.e., it took more current to produce given contraction force levels). Figure 2 also indicates that the loss of muscle performance appeared to correspond to the widening of the force-current loop recorded during ramped-increases and -decreases in current. The force-current loop vector showed a gradual phase change from 0 degrees for rested muscles to 180 degrees for fatigued muscles. The precise physiologic mechanisms for these changes in muscle performance characteristics are currently unknown and merit further study.

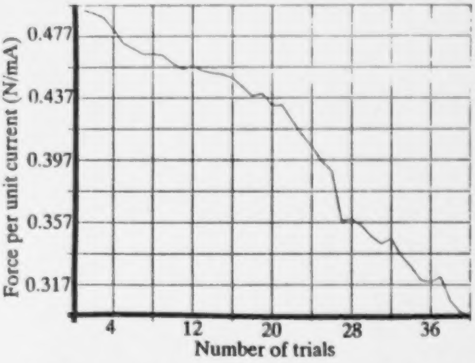

Figure 3. Plot of force per unit current as a function of number of trials

In conclusion, the force-current measurement system described in this paper appears to provide an objective technique to evaluate muscle performance for FNS. Such a system can furnish relevant information concerning the threshold current for contraction, force output per unit of current, smoothness of contraction, maximal force output, and endurance characteristics. This information can be used to predict one's capability for FNS use, how FNS performance changes with training and various other conditions (e.g., muscle temperature, medications, progression of a pathological condition), as well as to enable the design of accurate and reliable FNS control systems.

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Standardized Object Test for Quantitative Assessment of Hand Grasp Function Using the C.W.R.U Upper Extremity Neuroprosthesis

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ABSTRACT

Case Western Reserve University has developed and is utilizing an upper extremity Functional Neuromuscular Stimulation (FNS) system for the restoration of hand function in C5 / C6 complete spinal cord injured individuals. To date, 32 patients have been implemented with the hand system. We have developed of a clinical quantitative assessment tool referred to as a standardized object test (SOT) which is used to evaluate the minimal criteria of functional hand grasp. Five patients who are presently utilizing the FNS neuroprosthetic hand system were tested once per week over a 3 to 5 week period. The results of this test series indicate that users of the hand system have consistent performance during intra- and inter- test sessions and that the C5 level users have greater success using their hand systems compared to trying to perform tasks without using their hand systems. Ongoing assessment of the data is proceeding.

INTRODUCTION

The Standardized Object Test (SOT) is essential in determining a patient's ability to *minimally* operate their neuroprosthetic hand system. If a patient is unable to successfully use their hand system over a short range of motion, he cannot be considered for further functional testing and training. The test consists of six objects each having various weights, sizes, and textures. The objects are chosen such that each object represents a particular level of difficulty for each grasp. A patient is required to acquire, transport, and release each object as many times as possible in a thirty second period. The recorded frequencies are the number of successful completions and the number of failures. From these, the rate of success for a particular task may be calculated.

The SOT is designed to eliminate variables which may affect the isolated performance of the hand system, such as fatigue of palmar or lateral hand grasps, or fatigue of the patient's proximal musculature. Measurements, test equipment, and test location are to be maintained as consistently as possible, in order to determine a comparison of performance over time. With these precautions, it is hopeful that successful completions of the SOT objects will indicate success of the system. Concurrently, and just as important, failure of any of the SOT objects indicates an inadequacy in the patient's system, such that adjustments or repairs, and retesting should follow.

OBJECTIVES

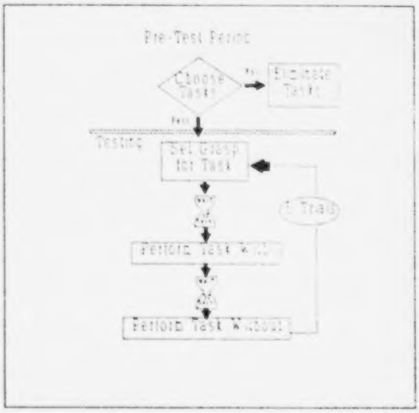
The objectives of the SOT are:

1) Determine whether patient performance is consistent across time, both with and without hand system.
2) Determine the variances in performance across patients, both with and without hand system.
3) Compare the differences in patient performance with versus without their hand system.

METHODOLOGY

Prior to testing a patient on a particular test date, force measurements of both palmar and lateral grasps are measured (ten measurements of each grasp prior to the test, five measurements of each grasp afterward). In taking these measurements, the shoulder is adducted to zero, the elbow flexed at 90°, forearm in neutral position, and the wrist at 0°. Each object, ideally, is designed to measure a particular facet of the FNS system.

Patients are allowed a pre-testing period just prior to the start of a particular test session. During this period, each patient could develop their strategies for moving each object. Thirty seconds are allowed for each pre-test period, although patients are allowed extra time to practice if they so desire.



Flow chart of events during SOT

In the SOT, the patients are given thirty seconds to move as many objects from the acquisition area to the release area of the test board as accurately as they can.

A description of the tasks are as follows:

A) Block Test (palmar grasp) - Patient is required to pick up the object with a palmar grasp and drop it over the test box barrier and into the box.

B) Disk Test (lateral grasp) - Patient must pick the object up by grasping the metal disk portion with a palmar grasp.

C) Videotape Test (palmar grasp) - With this object, the patient must pick up the tape case in its upright position, transport it without rotating his wrist to facilitate transport, and set the case down in its upright position on top of the test box.

D) Peg Test (lateral grasp) - Patient must pick the peg which is standing upright in a shallow drilled hole in the acquisition area of the test board. The object is then transported and dropped in the test box.

E) Cylinder Test (palmar grasp) - Using the palmar grasp the patient is required to move the cylinder in its upright position to the top of the test box without rotating his wrist or touching the test box barrier.

F) Fork Test (lateral grasp) - The patient must grasp the fork handle and push downward, using his entire arm and shoulder musculature.

RESULTS

Utilizing a Chi-squared analysis, we administered the SOT with five patients for at least 3 and not more than 5 consecutive weeks. The test results are displayed on the following tables. Table I displays the tasks that were able to be accomplished with and without using the hand system, Table IIa and IIb contrasts consistency of performance within test session across tasks, and Table III contrasts consistency of performance across test dates for each test task. The results indicate that the C5 patients can perform more tasks with their hand systems than without and all patients show near 100 % uniformity given tasks within a test session and across session. A 95 percent confidence interval was used for the chi-squared analysis.

Task	JJ	MH	RM	SA	TZ
Blocks	y/y	y/y	y/n	y/n	y/n
Cyl.	y/y	y/n	y/n	y/n	y/n
Disk	y/y	y/n	y/n	y/n	n/n
Fork	y/y	y/n	y/n	y/n	n/n
Peg	y/n	y/n	y/n	y/n	y/n
Tape	y/y	y/n	y/n	y/n	n/n

y=yes can perform task, n=no cannot perform task; numerator=with hand system, denominator=without hand system

Table I.

Task	JJ	MH	RM	SA	TZ
Blocks	5/0	4/0	4/0	3/1	3/0
Cyl.	4/1	4/0	4/0	4/0	3/0
Disk	5/0	4/0	4/0	4/0	*/*
Fork	5/0	4/0	4/0	4/0	*/*
Peg	5/0	4/0	3/1	3/0	3/0
Tape	5/0	4/0	4/0	3/0	*/*

WITH FNS SYSTEM

numerator=sessions tasks were performed consistently; denominator=sessions tasks performed below 95% confidence interval

Table IIa.

Task	JJ	MH	RM	SA	TZ
Blocks	5/0	4/0	*/*	*/*	2/1
Cyl.	5/0	*/*	*/*	*/*	*/*
Disk	2/1	*/*	*/*	*/*	*/*
Fork	*/*	*/*	*/*	*/*	*/*
Peg	5/0	*/*	*/*	*/*	*/*
Tape	3/0	*/*	*/*	*/*	*/*

WITHOUT FNS SYSTEM

numerator=sessions tasks were performed consistently; denominator=sessions tasks performed below 95% confidence interval

Table IIb.

Task	JJ	MH	RM	SA	TZ
Blocks	Y/Y	Y/Y	Y/*	N/*	Y/N
Cyl.	Y/Y	Y/*	Y/*	Y/*	Y/*
Disk	Y/N	Y/*	Y/*	Y/*	*/*
Fork	Y/*	Y/*	Y/*	Y/*	*/*
Peg	Y/Y	Y/*	Y/*	Y/*	Y/*
Tape	Y/N	Y/*	Y/*	Y/*	*/*

y=yes can perform task, n=no cannot perform task; numerator=with hand system, denominator=without hand system

Table III.

CONCLUSION

The utilization of the FNS hand system must be rigorously evaluated on a functional basis to determine its usefulness to patients in a real-time daily activity environment. The SOT is a means to determine if the hand system can be used to acquire, move and release objects in a controlled environment. If a person demonstrates he is able to operate the hand system and pass the SOT, he could begin the functional evaluation portions of the program. The SOT is a tool that will indicate a minimal level of hand system proficiency.

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SENSORY FEEDBACK AND AUTOMATED GRASPING FOR A VOCATIONAL ROBOTIC WORK STATION

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I. INTRODUCTION

Recently, our work has focused on the development of the Robot Motion Editor, a user friendly, voice controlled interface for a vocational robotic workstation [2]. The Robot Motion Editor gives disabled users the ability to teach a robot position trajectories and motions corresponding to the location of objects in the work place. Once a motion is taught, it can be stored for later retrieval so that with one spoken phrase the motion can be replayed.

In parallel with the work on the user interface, work on sensory feedback is also taking place to enhance the system's utility. Several problems are inherent in robotic workstations when no feedback is employed. First, while the user can easily position the robot gripper in the general vicinity of the object, orienting the gripper exactly as needed can be a formidable, time consuming and often frustrating task. Assuming that this is possible, successful repetition of this motion requires that the object remain exactly where it was when the motion was taught. Even if the object has not moved, selection of a taught motion will not produce the original result unless a robot with a high degree of accuracy and reliability is used. The robot arm used in this project, the UMI-RTX, does incur error with time.

Our objective is to incorporate sensors into the gripper to reduce the difficulty of positioning the robot when preparing the robot for grasp and to alleviate the need for precise positioning of the gripper and of objects. The information provided by the sensors enables the implementation of automated grasping so that when teaching, the user only needs to place the robot in the general vicinity of the object. Once the gripper is near the object (having been moved either under direct user control or as a result of a pre-taught motion), automated grasping can be invoked so that the object can be precisely located and retrieved. This should improve ease of use, reliability and safety.

II. BACKGROUND

Several designs have been proposed to automate grasping for the motor impaired user. Valettas *et al.* [6] place retro-reflective photo-electric sensors on each finger of the gripper, parallel to the line in which the finger points, to detect the presence of objects within a 7 cm range. When automatic grasping is invoked, these sensors are used to locate the object through the use of trial and error translations of the gripper and to center the gripper about the object. A single thru-scan sensor placed perpendicular to the fingers is used to determine if the object is within the gripper. A similar approach is taken in the Spartacus Project [1].

A more comprehensive approach is described by Park and Leifer [3]. 12 infra-red proximity sensors, an ultrasonic sensor and a 6-axis force transducer are incorporated into the gripper for object localization, 3 dimensional template matching and automated stable grasping.

To understand the advantages of our design and how it relates to the designs described above, the major steps required to achieve automated grasping are reviewed. These steps, which should be accomplished as quickly as possible for the user who is waiting for immediate results, include [1,5]:

1. locating the object.
2. determining its spatial orientation.
3. determining a position for a stable grasp.
4. moving close to the object at the desired position with correct orientation.
5. centering the object within the gripper.
6. moving the gripper forward and closing its fingers around the object.

Park and Leifer [3] accomplish these steps with little prior assumptions about the object. To do this, a complete picture of the object and its orientation in space is determined using 14 sensors and a reference data base. Although the design by Valettas *et al.* [6] is simple to implement, maintain, and easy for the user to understand, its utility is somewhat limited. With minimal sensory data, this latter scheme assumes that the gripper is properly oriented with respect to the object when automated grasping is invoked. Such an assumption could seriously compromise the reliability of automated grasping because an object not fixed in place can rotate as well as translate. This scheme also assumes that the grasp is stable and that all objects are picked up in the same manner. In addition, the time required to locate and center the object within the gripper can be unnecessarily long due to the limitations of the sensors used in this scheme.

A middle of the road approach is taken here. More sensory data is obtained to reduce assumptions, but for simplicity, ease of implementation, and speed, some assumptions are still made so that a complete 3 dimensional representation of the object is not needed for automated stable grasping. Specifically, the goals are to minimize the time spent locating the object and the assumptions made about the orientation and size of the object, and to maximize the efficiency and reliability of automated grasping using a minimum number of sensors.

III. METHODS

Figure 1 shows a sketch of the robot gripper and the sensors used for automated grasping. These include two thru-beam and two retro-reflective photo-electric sensors, and one ultrasonic sensor. When automated grasping is invoked, the ultrasonic sensor is used to find the relative distance of the object nearest to the gripper through a simple rotation of the wrist in a single plane. During this rotation, data is collected on the time-of-flight of the ultrasonic echo as a function of sensor (wrist) angle for a 2 dimensional slice of the object. Echo time-of-flight is related to the distance between the gripper and reflecting surfaces, so the distances between the gripper and surrounding objects are obtained, and the nearest object is located. Since these distances are known, there is no need to locate the object via trial and error scanning. Once the distance to the nearest object is computed, the gripper can be quickly moved closer to it.

The information on the orientation, shape and edges of the detected object are also determined using the echo data. Edge location is possible because surface discontinuities cause discontinuities in the time-of-flight versus sensor angle data. The relationship between timing and angle is dependent on object shape and orientation. Such relationships can be determined for a variety of object shapes [4]. Assuming the surface of the object is fairly smooth, curve fitting of the echo data is performed and compared to these known relationships. The best fit curve will determine object surface shape and the orientation of the object with respect to the gripper. Having determined where the edges are and

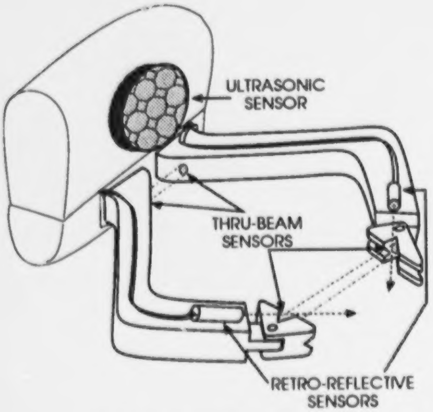

Figure 1 Sensor Configuration

what the shape of the object is, the width and center of the object surface facing the gripper is calculated. If this width is larger than the maximum width of the gripper, the gripper moves to the nearest corner to grasp the object from a different perspective. Again, computed distance information eliminates the need for trial and error searching to find the corner.

Once the edges of the object face nearest the gripper are determined, the gripper moves to the center of the face in preparation for grasp. The two thru-scan sensors embedded in the gripper are used to determine if the object is within the grasp of the fingers and to choose between two forms of grasp (finger tip versus full grip). One thru-beam sensor is located at the tip of the fingers and one at the base of the fingers (figure 1). The two retro-reflective sensors are high resolution sensors used as pseudo-touch sensors to insure that the gripper avoids collision while moving forward with the object inside its fingers. (The ultrasonic sensor cannot provide this information if the object inside the gripper blocks its view).

The gripper next moves forward to pick up the object. If either retro-reflective sensor detects something in the path of the gripper before the thru-beam at the back of the gripper detects the presence of the object being picked up, the gripper backs up and picks up the object with its finger tips. This will occur if the length of the gripper finger is greater than the object depth. For example, when a mouth stick lying on a desktop is being picked up, the retro-reflective sensors will detect the desktop before the gripper bumps into it and before the second thru-beam is broken. Alternatively, if the retro-reflective sensors do not detect any obstacles, the gripper moves forward until the thru-beam at the back of the gripper is broken by the object. If the thru-beam at the finger tips is not broken while that at the base is, this signals the presence of a small object and the gripper backs up to pick up the object with its finger tips. Because the gripper position at which the two thru-beam sensors were broken is known, the finger tips can be centered around the object. In this way, some 3 dimensional information about the object is determined so that a book is grasped using the entire length of the finger and the base of the gripper as a support for stability, while a mouth-stick, which would otherwise slip through the fingers, is grasped with the finger tips. Finally, the gripper is closed and the object is acquired.

IV. DISCUSSION

One of the major advantages of this scheme is that one rotation of the wrist about a single degree of freedom replaces the need for repeated time consuming translations of the gripper. Since object orientation can be quickly determined, there is no need to make any assumptions about the object's orientation with respect to the gripper. Efficiency and reliability should be substantially improved with the use of the ultrasonic sensor and its ability to determine distance.

This design relies upon the intelligence of the user. Specifically, it assumes that a stable grasp is achievable with the gripper positioned at the height at which automatic grasping is invoked, rather than determining this by taking more time to collect additional data or by using stored data [3]. For a symmetrical object such as a book, the user can easily position the gripper so that it is at about half the height of the book when first invoking automated grasping. It is assumed that precise positioning of the gripper at this height is not necessary for a stable grasp. Secondly, the design assumes that the correct object is picked up. If two objects are close together, it is possible that automated grasping might pick up the incorrect object. Comparisons with a data base [3] or some form of identification marks could prevent this error, but speed and ease of implementation might be sacrificed at the cost of more reliability. If the incorrect object is picked up or is about to be picked up, the user can always take corrective actions using the Robot Motion Editor.

V. FUTURE WORK

Testing will be performed to study the reliability and efficiency of automated grasping and to determine appropriate gains and thresholds settings. If misunderstandings on the part of the robot are common or if stable grasp is not routinely achieved, it may be necessary to obtain more data on the object with the sensors or to employ some of the more sophisticated techniques proposed by Park and Leifer [3].

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MOBILE ROBOT SYSTEM FOR REHABILITATION APPLICATIONS

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INTRODUCTION

A mobile robot platform is under development which can serve as a semi-autonomous base for task guidance systems developed to aid people with cognitive impairments. These task guidance systems interactively provide instructions and cues to assist people with cognitive impairments to independently perform activities. The goal is to allow them to complete a task which they could not otherwise do without supervision and assistance from others(1).

Previous research with task guidance systems has included trials with both stationary and portable configurations. This research has demonstrated the desirability of making such task guidance systems independently mobile with a large degree of autonomy. The mobility criteria for task guidance systems not only include the ability to independently pass from one point in the environment to another while avoiding random obstacles, but also the ability to follow or lead an individual to a desired location within the environment.

The rationale for these criteria is demonstrated by the following example based on an ongoing trial with a task guidance system. Consider an individual with cognitive impairments resulting in spacial disorientation and memory deficits. In guiding this person through a janitorial task the task guidance system may have to lead the person from one room to the next and additionally monitor their position to ensure that they are following.

The autonomy and tracking requirements are of importance for mobile robots intended for use by cognitively able people (perhaps with motor impairment) as well as for users with cognitive dysfunction. For example, the ability to autonomously move from any point in an environment to another without requiring continuous input from a user is critical in lowering the conscious demands for robot control to acceptable levels. In a similar fashion, the ability of a robot to "track a companion" frees the companion from providing continuous directions when they want the robot to accompany them.

PREVIOUS WORK

Many of the essential technologies and knowledge for the mobile robot platform have already been developed and tested in another application focused towards the autonomous operation of mobile robots in hazardous environments (such as a nuclear power plant). This work has included the development of navigation routines for obstacle avoidance over the past several years(2,3). The outcome of this work has resulted in a system which is capable of navigating within the laboratory setting at high speeds through an environment cluttered with unknown (and even moving) obstacles.

The obstacle avoidance system has been installed and tested on a Cybermation K2A mobile robot. It uses a ring of twenty four ultrasonic sensors around the mobile robot base to collect data on the location of obstacles in the robot's immediate surroundings. An internal memory representation of the environment (map) is continuously updated with these readings. The update cycle for the internal map and the utilization of the map by robot to plan its path occurs independently. This parallel architecture, separating the data collection and data usage routines, allows for flexibility in sensor selection when optimizing for a particular environment or task (e.g. the ultrasonic sensors can easily be substituted with other types of ranging sensors).

The obstacle avoidance software, written in the C programming language, is based on algorithms which treat obstacles as repulsive forces and the destination as an attractive force. As the robot moves and updates its internal environment map, it evaluates the repulsive effects of all the mapped objects within a three meter range centered on its current position in the map, and subsequently determines the best path toward the destination. The repulsive/attractive interpretation of the environment allows the robot to navigate local obstacles such as walls and random objects in its path at high speeds in real time. The algorithm will guide the Cybermation K2A robot through an obstacle laden path with an average speed close to the unit's maximum speed of 0.78 m/sec

MOBILE ROBOT SYSTEM DEVELOPMENT

The results of these developments are now directly being transferred to a mobile robot platform for use in development related to rehabilitation applications. This system is largely based on commercial hardware and comprised of the following subsystems:

Denning DRV-1W Mobile Robot with associated:
- infra-red absolute positioning beacon system
- remote radio link
- ultrasonic sensor ring with 24 transceivers

Obstacle Avoidance Software
Path Planning Software
Companion Tracking System

The transfer of software to the Denning has been simplified by its high degree of similarity with the Cybermation used in the previously described application. The Denning comes with an integrated ring of 24 ultrasonic transducers almost identical to that developed for the Cybermation. The Motorola 68000 on-board controlling computer, delivered with the Denning base, has been replaced with an Intel 80386 computer identical to the one used on the Cybermation to further enhance their similarities and increase the computational performance of the Denning.

In addition to the implementation of the obstacle avoidance system on the Denning, software has been developed for path planning. This software uses a map of the environment to plan an optimal path between any two points (i.e. the current location and desired destination). The path planning algorithms have been designed to operate on the same map of the environment used by the ultrasonic sensing and obstacle avoidance software for compatibility. An important outcome of sharing a common map is that the path planning system utilizes a dynamic representation of the environment which is constantly updated as the ultrasonic sensors detect unknown obstacles or the removal of known obstacles. The installation of the path planning system includes an infra-red beacon positioning system for determining the robot's absolute location.

FUTURE WORK

Integration of Obstacle Avoidance and Path Planning. While following the pre-planned path to a destination the robot may be required to avoid numerous unknown obstacles. At all times it must be able to resume the task of reaching its target once the local obstacles have been successfully navigated. This may require a new path plan if the pre-planned path is no longer possible due to the presence of obstacles. This situation would likely require a new path calculation using the updated internal map (as well as absolute position information). The manner in which the robot gets back on course, or determines whether a new course is more advantageous, needs to be determined.

Companion Tracking. The companion tracking system will consist of a non-physical link between the robot and the user (companion) which will enable the robot to remain in contact with the assigned user regardless of background clutter and other humans in the vicinity. Companion tracking will operate in either a lead or follow mode, and have the ability to switch from one mode to the other to best fit the needs of the user. The design for the tracking system has not been finalized, but one option is the shared use of the infra-red beacon positioning system. Another possibility being pursued is the exclusive use of a transponder system based on radio frequency triggered ultrasonics. Companion tracking is viewed as a vital part of the mobile robot system.

Clinical Trials. The first clinical trials of the mobile robot are planned in conjunction with its use as a base for the previously described task guidance system. It is initially planned to test the system at the Ann Arbor Veterans Administration's Nursing Care Unit with geriatric patients having varying levels of cognitive dysfunction. Proposed goals for these trials include guidance through a portion of a patient's daily activities covering such area as personal hygiene, scheduling of daily activities, transportation, and any other tasks required for independent functioning.

DISCUSSION

The modified Denning robot equipped with path planning, obstacle avoidance, and companion tracking capabilities will provide a system with intelligence and a substantial degree of autonomy. The level of autonomy required for most applications will depend in part on the cognitive abilities (as well as attitude) of the user. A much lesser degree of autonomy is needed in the case of a user who only has motor impairment as compared to a person with cognitive and perceptual difficulties. Even in the latter case, though, it can be expected that the user has a great deal of intelligence which can be used to help guide the robot and soften the requirement for autonomy. For example, consider a user who has severe memory problems and is easily distracted. It may be required that the robot guide this person to a desired location, but if in doing so the robot became disoriented, it might be able to ask its "companion" for information about their current location (thereby using the persons sensory system as an augmentation of its own).

The application of a mobile robot as part of a task guidance system for cognitively impaired people leads to a new conceptualization of robot control (or more generally assistive device control). The most common control model views the user as inputting a control signal to the given device (such as a robot) through an interface (Figure 1). With the "mobile robot guidance system" (MRGS) the conceptual model of the system is better represented by the diagram shown in Figure 2. In this model the human and MRGS are viewed as co-dependent components of a functional system working together for the completion of the targeted activity.

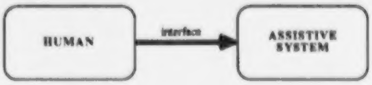

Figure 1: Standard Control Model

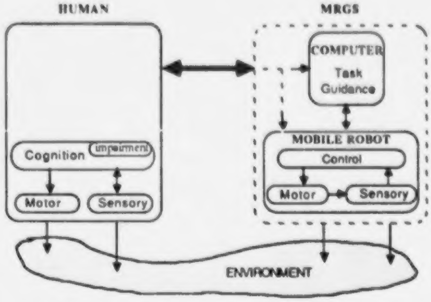

Figure 2: MRGS Conceptual Control Model

The development work described here is intended to contribute to the development of intelligent and semi-autonomous robot mobility which can be applied in a range of assistive systems for people with cognitive and/or physical impairments. The goal of this work is not to develop hardware specific solutions, but rather general solutions to the described problems which can be applied to a range of hardware systems.

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DEVELOPMENT OF AUTOMATED GRASPING END-EFFECTOR FOR ROBOTIC AID USING MULTIPLEXED INFRARED SENSORS

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INTRODUCTION

The Louisiana Tech Center for Rehabilitation Science and Biomedical Engineering is actively engaged in searching for ways to improve the everyday living conditions of persons with disabilities. Among other approaches, the Center is exploring ways of applying robotics to this complex problem. Other groups such as Stanford University, Mechanical Engineering Design Division (1), Rehabilitation R&D Center, Palo Alto Veterans Administration Medical Center (1) and University of Toronto, Department of Mechanical Engineering (2) have reported robotic aids using voice command and automated grasping systems. Although similar in some aspects to previous aids, the system reported here uses analog signal multiplexing to process a larger number of sensor inputs.

Several robots have been evaluated at the Center and rated according to their potential usefulness in the rehabilitation arena (3). Universal Machine Intelligence's RTX robot, which is a six-degree-of-freedom SCARA robot, was selected for further development. In order to make the robot as user friendly as possible to the disabled individual, two enhancements to the RTX have been implemented. The first enhancement is voice control resulting in all robot actions being initiated by voice commands. This has been implemented by using the IBM Voice Communications Package to provide a voice-activated interface (3).

The second enhancement involves automated searching and grasping capability along with collision avoidance for retrieving household objects. Having these capabilities reduces the number of robot commands needed to maneuver the robot end-effector in the vicinity of the object to grasp. These capabilities are being implemented by using infrared emitters and detectors as sensors.

HARDWARE

TRW OP598A NPN plastic silicon phototransistors and TRW OP290C infrared emitting diodes are used as sensors on the robot arm end-effector. These sensors were chosen for their low cost, simplicity, and high reliability. For development purposes, the sensors have been located on the end-effector in a flexible mounting scheme that facilitates experimentation with several arrangements. Sensor locations to collect maximum information about the object to be grasped are being initially investigated.

An analog multiplexer circuit was built that allows the use of up to 32 channels of data for collision avoidance and collecting information about the object to be grasped. The multiplexer circuit board is mounted under the "elbow" of the robot arm in an area that will provide it with maximum protection. The 0-5 volt sensor signals are multiplexed to an analog-to-digital (A/D) converter which is connected to the external computer. The information is then available to the controlling software in the form of positive integers in the range of 0 to 4096 for each channel.

Communication through an RS-232 cable takes place between the computer serial port and the robot serial port. The sensor data are collected and sent from the multiplexer circuit through a ribbon cable in the robot arm to an ancillary port on the robot. Another ribbon cable at the ancillary port is connected to the A/D board in the computer.

SOFTWARE

The RTX is supplied with a run-time library of routines to facilitate programming the robot. A PASCAL language interface to call those library routines is also provided. The interface was rewritten in the C language to facilitate the use of C for all software development. Consequently, the library routines to control the robot can be called from within C programs. Some routines are used to write information to the robot and others to collect information from the robot. For example, the motors that drive the arm are controlled by sending them new encoder counts. This type of information is constantly being sent back and forth between the computer and the robot during robot arm movement. The following example illustrates how robot arm movement is initiated in numeric mode from within a C program. The functions written in capital letters are located in the RTX run-time library.

```
void NumArmDown()
/* numeric mode arm down motion */
{ /* begin NumArmDown */
/* read encoder counts from all motors */
   for (i=0; i<7; i++)
      ARM_READ(i, CURRENT_POSITION,
      &EncoderCount[i], &OK);
   WaitTilNotBusy();
/* if arm is already at bottom, then print error
msg and exit */
   if (EncoderCount[2] <= -3524) {
      printf("can't move Down\n");
      exit(0);
   }
```

The sensor data are available through a software construct called a structure. Each time a "scan" of the sensors takes place, the new values collected by the A/D board are placed in this "sensor" structure automatically and are then available to an automated grasping algorithm (AGA).

The AGA uses the information in the "sensor" structure to make decisions on how to move the robot arm. The AGA knows when a sensor has "seen" something by comparing the values in the "sensor" structure with pre-determined threshold values. For instance, the AGA may be guiding the robot arm forward, constantly checking the "sensor" structure for values above the threshold values, when a sensor detects an object. When this happens, the value in the "sensor" structure representing the detecting sensor rises above the threshold value. Based on updated information in the "sensor" structure, the AGA can make intelligent decisions on where to move the robot arm next.

STATUS AND FURTHER WORK

One sensor arrangement and its corresponding grasping algorithm has been implemented and tested in a prototype system (3). The system was able to detect and center the robot end-effector about several objects such as books, cans, and other objects that were small enough to fit inside the jaws on the robot. Performance in terms of successful grasps was improved over that achieved with voice commands alone. In addition, the number of voice commands needed to grasp an object was reduced using the sensing capability. One limitation involved having to place the end-effector in an initial position such that it was near the object to be grasped with the jaws oriented in a horizontal plane. Another problem was hitting objects with the robot arm when maneuvering in tight spaces.

Of the ten sensor data channels available in the prototype system, eight were used by sensors to collect data about the object to be grasped. The two remaining data channels were not enough to implement a complete collision avoidance scheme. The new circuit described in HARDWARE facilitates the implementation of more sophisticated sensor arrangements to relax the constraints on initial position of the robot end-effector and the use of dedicated sensors for collision avoidance.

The multiplexing of sensor signals provides an easily implemented method of obtaining information from a large number of sensors on the end-effector without having a large number of signal cables between the robot and the computer that would otherwise be necessary. Access by the AGA to a more detailed representation of the environment around the end-effector allows a higher degree of control of the end-effector. This leads to a reduced workload on the disabled individual and increases speed and accuracy involved in grasping an object.

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TODUS: AN ENGLISH INTERFACE WITH REHABILITATION POTENTIAL

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Experience with English language interfaces provide good-fit criteria. A rehabilitation example is discussed to show it is a good-fit for an English interface. The Multiple Cooperating Agents Project is a model for operator control and its English interface, TODUS, accepts language similar to that required for rehabilitation. Samples of language accepted and implementation data are provided. From this we conclude that TODUS has good potential for rehabilitation.

INTRODUCTION

Having computers understand human languages has long been a dream. Formal language interfaces, e.g., COBOL, are one of computer science's great achievements. However, natural language interfaces (NLIs) such as English, have proven more elusive. However, progress has been made in database interfaces, machine translation and document understanding. And, there is great promise for voice interfaces for rehabilitation.

Types of NLI tasks differ greatly, so we have analyzed requirements and developed criteria for good NLIs. Rehabilitation applications fit the criteria well. We describe an experiment with our NLI which shows potential for rehabilitation.

SOME RELATED WORK

Task-oriented dialog characteristics have been studied (4,5,6,8). The lessons learned from robot NLIs are very useful for rehabilitation and successful experiments have been reported (2,3,9).

NATURAL LANGUAGE INTERFACE CRITERIA

We must carefully match technology to a problem to achieve a "good-fit". Each candidate NLI must be analyzed for types of tasks, language requirements, ability to construct a shared model, alternative technologies, need for spoken language, use by a non-casual user and likelihood of acceptable performance.

Rehabilitation provides many opportunities. Consider a quadraplegic with access to a workcell equipped with a robot arm for daily living tasks. Such a useful keyword-driven interface was demonstrated in a recent Stanford-V.A. project. Cerebral Palsy and Parkinson's patients could benefit from NLIs. The non-motor impaired, but still physically handicapped, could benefit. Blind persons could control equipment the same way as quadraplegics. Hearing-able supervisors could communicate better with deaf employees. In fact we are planning an Army metal working shop system where the hearing able use an NLI to describe tasks and an optical disc to retrieve previously constructed sign language sequences.

EXAMPLE

Consider the quadraplegic example using our criteria:

Types of tasks

We can identify precisely the tasks to be performed--getting a drink of water, controlling a toothbrush, etc. They are modest in number and not open-ended. Natural physical boundaries are associated with the objects and what you can do with them.

Language requirements

We can obtain language data used to solve problems such as "Please get me a drink of cold water" and it is a non open-ended subset of NL. NL boundary issues are constrained naturally by the physical events in the workcell microworld. An NL recognizer can be constructed, as we demonstrate below.

Shared model

The patient can see the objects and their states (e.g., the glass is empty). The robot's world model and the NL discourse model can be updated so dialog is relevant. The patient and the system can provide constructive feedback. Results of actions are consistent and predictable allowing the patient to adjust to the NL.

Alternative technologies

There are few. One is mouthstick control of a keyboard and the NL alternative is clearly superior.

Spoken language

A voice frontend is the preferred input method.

Non-casual user

The patient is a cooperative and

committed user allowing system and NL boundaries to be learned quickly.

Acceptable performance

Performance data for the robot and the NL subsystem are available. Robot actions are 'pick and place' and well established. Our NLI demonstrates a language level which is adequate. The likelihood of achieving acceptable performance is excellent.

This example represents a large class of applications, namely operator control of equipment. We describe next an apparatus designed to investigate this class.

THE EXPERIMENT

The Multiple Cooperating Agents Project deals with a workbench world with robots as agents and hammers, screwdrivers, nails, screws and workbenches as objects. Its NLI is TODUS, a Task-Oriented Discourse Understanding System (1,3,7).

TODUS consists of 6600 lines of PASCAL written over 12 person-months. It runs on a popular personal computer chip - a 6meg Motorola 68020 and has a voice front-end. Its vocabulary is about 100 words and response time is negligible.

A SAMPLE OF LANGUAGE ACCEPTED BY TODUS

We provide a sample recognized by TODUS. Note that TODUS handles sentence fragments, multi-verb expressions, several question types and maintains continuity of context to resolve pronoun and elliptical references. Language constructs are similar to those required for rehabilitation.

- First insert a nail, then a screw.
- Use the red hammer to insert a green nail into the blue bench.
- With the blue screwdriver, screw a green screw. Into the red bench. Upper right corner.
- Hammer a nail into either bench. Hammer a nail into the red bench, anywhere. Screw a screw somewhere in the upper row of the blue bench.
- Hammer a green nail into the red bench. Now another one into the blue one.
- Is there a green nail in the blue bench?
- How many blue nails are there in the blue bench? Where are they?

DISCUSSION AND CONCLUSIONS

We have developed criteria for assessing whether an application is a good candidate for a successful NLI. The rehabilitation domain has good candidates for NLIs.

Such applications are members of the operator-control class of problems. An experimental domain using robots in a tool-object setting has been established for this class. TODUS, its NLI, has been demonstrated to have good syntactic and semantic coverage and is compact and efficient.

Language recognized by TODUS in its tool-object domain is similar to that in certain rehabilitation applications. Quadraplegics, Cerebral Palsy, Parkinson's, certain blind and deaf patients, and wheelchair-bound patients could benefit from the TODUS approach. Thus, TODUS is an NLI with good potential for rehabilitation.

ACKNOWLEDGEMENTS

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INTEGRATED ROBOTIC ASSISTED ENVIRONMENT

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ABSTRACT

The majority of research currently being done on robotic interfaces for persons with disabilities involves costly computer and mechanical equipment. A price tag of $15,000-$40,000 is not unusual. The system described below offers a reasonably priced way to deliver instruction on basic robotics and its uses in the area of Rehabilitation technology. The total cost of the robot, host computer, and workcell basics was less than $8,000. A microprocessor driven 8-valve pneumatic controller ($1,500) adds versatility as well as more learning experiences.

INTRODUCTION

Integrated Robotic Assisted Environment (IRAE) was initiated in the spring semester, 1988 at the Center for Rehabilitation Technology, University of Wisconsin-Stout. IRAE addresses three main objectives: first, illustrating how robotics can enhance a worker's ability and how a worker can enhance a robot's abilities, second, to illustrate how robotics can assist persons with disabilities and third, to create an environment where the robot would assist in doing both industrial and clerical tasks.

The robot used for this assisted environment is a Rhino XR3 produced by Rhino Robotics, Inc. in Champaign, Illinois. The robot is mounted on a moving platform, which is driven by an auxiliary motor activated by the robot controller. The motor directly drives a gear that engages a chain stretched across the table. The platform has four metal wheels that ride on a set of garage door rails. By using commonly available materials, an economical 8 foot long slide table was created.

In order to stabilize the robot and increase its repeatability of position, a pneumatically activated brake system is mounted to the robots aluminum platform which clamps the moving platform to the track when a destination is reached. The air brake is activated via a solenoid air valve, the power for which is supplied by one of the twenty volt dc auxiliary ports on the robot controller.

An adjustable height table for performing computer entry and other clerical tasks is moored on one side of the robot table. On one side of the track, the robot can perform clerical tasks on this adjustable height table and industrial tasks on the other side on its own table. The clerical table is adjusted by activating a switch which controls two electrical powered lead screws. The table can accommodate a wide range of users including: young children, wheelchair users, people using standard office furniture, or even a standing worker.

ROBOT TASKS

The robot configured in this integrated environment can perform many different tasks. On the industrial side of the table, the robot performs such tasks as placing and removing parts from pneumatic testing fixtures, holding pieces and panels to be spray painted (the spray paint gun is controlled by a solenoid valve activated by the robot controller), holding sheet stock during a drilling operation and doing various picking and placing operations.

When the robot swings to the clerical table it performs such tasks as stapling paper, moving paper to various locations, retrieving resources for the user. The linear motion provided by the slide table allows the robot to easily insert disks into the disk drive of an IBM computer, which is also used as the host computer for storing robotic programs.

Two students were involved in the initiation of IRAE which included design and construction of the adjustable height clerical table, design and construction of a slide table, and preliminary programming of various robotic tasks.

FUTURE WORK

Future work will build upon this preliminary activity including: further, more detailed programming of robotic tasks, the possibility of adding an end effector changing station so that the robot can change its end effector or better perform the various tasks. Research will be done on the various problems inherent in this system, particularly the changing of robot coordinate points for various programs as the clerical table height is adjusted, in other words, how can a programmed routine be quickly and easily modified to perform the same tasks for persons who have the table at two different heights.

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APPLICATIONS OF THE CURL PROGRAMMING ENVIRONMENT

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ABSTRACT

A programmable robotic workstation has been developed for use in the educational and vocational settings with severely physically disabled individuals. In such settings, the intelligence of the user is supplemented with the manipulation power of a robot in order to carry out complex tasks such as block play, cooking, science experiments, and semi-automated assembly and inspection. This paper presents an overview of the robot system and the CURL programming environment, and a brief discussion of the tasks carried out to date.

SYSTEM CONFIGURATION

The work at the University of Cambridge has been primarily involved with the development of a programmable robot system for application in the educational setting with severely physically disabled children.[1,2] Figure 1 illustrates the current system configuration. The system comprises a UMI RTX robot modified with simply proximity sensors to aid in the grasping of objects, a purpose-built vision system to identify coded markers which may be attached to objects, and a PC-based robot programming environment CURL from which to program and command the robot. A variety of input devices are supported including single and multiple switches, headswitches, standard and modified keyboards, and natural voice input.

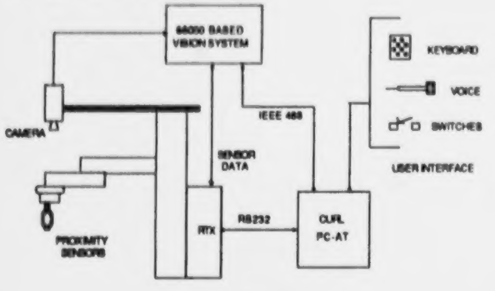

Fig 1. System Configuration

DEVELOPMENT OF CURL

It has been through the direct experience of applying robotics to the tasks described in this paper that the shortcomings of current rehabilitation and industrial robotic programming techniques have become evident. Industrial robot languages do not support an interactive approach to programming/control which is essential for rehabilitation applications. It is felt that the ability to specify easily the robot tasks in terms of the desired changes to the disabled user's environment is a necessary feature for any programmable robotic workstation. Coupled with the need to be able to program and recall sequences of robot actions, is the requirement that the disabled user maintain ultimate control over the robot's motion in order to modify the course of action in the event of a mishap or in situations where preprogrammed actions are not appropriate. This amounts to a merging of the traditional manipulator and robotic workstation approaches to rehabilitation robotics, an issue which has been largely overlooked by previous research efforts.

The philosophy taken in the development of CURL, which originates from the work on Calvin,[3] has been to keep robot programming as simple, fast and interactive as possible. Hence, CURL has been developed as menu-driven, task-oriented interpreter offering the user a natural language subset from which to program and command the robot actions.[4,5] Facilities are also available to allow the user to have direct control of the robot end-effector in cartesian, tool, cylindrical, and joint space.

A data base has been designed into the language to enable information regarding the robot's environment to be stored. Objects need not be described by unique identifiers but may take on more general identifiers such as **block** or **cup**. The objects may be further described by means of adjectives in order to distinguish between them in the event that a number of objects have the same general identifier. For example, in a task which requires a number of blocks to be sorted by colour, the individual blocks may be given the general identifier **block** and descriptors such as **red**, **yellow** and **green** may be assigned in order to identify each object in a unique manner. For example, the command

look for the red cup.

activates the vision system and updates the data base entry corresponding to **the red cup**.

In addition to supporting the descriptions of objects using basic adjectives, the CURL language also supports the use of comparatives and superlatives. For example, relationships between objects may be stated using commands of the form,

the red block is heavier than the yellow block.
the green block is heavier than the red block.

This information may be used in a conditional test to identify the object to be operated on by a motion command. For example, given the following program segment,

if the green block is heavier
than the yellow block
pick up the heaviest block.

the CURL interpreter evaluates the conditional to be true and deduces that the **heaviest block** is the **green block**. Hence, the robot proceeds to pick up the **green block**.

A series of motion primitives are provided in order to manipulate objects and to move the robot around the work environment. Sufficient intelligence is incorporated into the motion planned to ensure that the tasks are carried out properly. Further commands are available in order to give directional control of the end-effector. For example, the command

move out 250.

results in a straight-line motion along the approach axis of the end-effector for a distance of 250 mm.

CURL has been designed to give the disabled user interactive control of all features of the system. This has been accomplished through the introduction of (i) a **drive** command giving the user direct control of the device, (ii) an interactive pop-up menu system for accessing preprogrammed robot actions, basic system primitives, and standard applications such as wordprocessors and spreadsheets, and (iii) a command line facilitating command entry by keyboard or voice input.

REVIEW OF APPLICATIONS

There have been seven application areas, covering some 25 tasks, which have been addressed during the course of this research project. These applications, which were used to test and extend the various versions of the CURL environment, may be grouped as follows: (1) Early Developmental Education, (2) Interactive Game Play, (3) Painting, (4) Interactive Chemistry Experiments, (5) Cooking, (6) Feeding, (7) Vocational Rehabilitation

In the area of Early Developmental Education, tasks have been designed to teach concepts such as (i) cause-effect relationships, (ii) colour, shape and size identification, (iii) sequencing, and (iv) planning. The tasks were structured such that the robot initiated an action and prompted the child for the yes/no response that was appropriate to the subsequent action. All of the tasks were preprogrammed in CURL and modified to suit the abilities of the children who used the robot. The ability to adapt a task and its method of control to a child's abilities proved to be a strong feature in CURL. It is felt that the teacher must remain an integral part of learning in early developmental education, and he or she would be expected to provide the main source of encouragement for the child's learning process.

Interactive Game Play tasks have included a draughts board game called Fox and Hounds and the Tower of Hanoi puzzle. The first task makes use of the CURL facility for specifying GOAL locations and relationships between GOAL locations. In addition, the vision system was used to identify the position of the board and the positions of the game pieces. These tasks provided the students with a means of social interaction with peers, in addition to exposure to concepts such as task analysis and action sequencing.

A painting task was developed to enable severely physically disabled students to carry out a simple painting exercise. The vision system was used to identify the location of three modified paint brushes and a sheet of drawing paper. The student who used this application was capable of only single switch selection. This necessitated a very structured approach to the task. Subsequent versions of CURL have facilities for direct control of the end-effector that could be used in a more conventional approach to painting.

A series of Interactive Chemistry Experiments was carried out by a student with Cerebral Palsy who was able to use a guarded keypad as an input device. The tasks involved the manipulation of standard Pyrex test tubes, Pyrex beakers, a Pyrex funnel and a spirit burner. With the exception of placing the funnel on a small stand to stabilise its position, the objects that were used in this task were unmodified. The experiments that were carried out ranged from observing the colour changes that take place by mixing and heating solutions of sodium thiosulphate and copper sulphate, to observing the effect of heating match heads in a test tube. A total of ten such experiments were carried out. The student selected preprogrammed options, which were specific to the particular experiment, from a menu and supplemented these selections with direct control of the device as necessary. For example, on one occasion while pouring liquid into a test tube an air lock trapped the solution in the funnel. In order to rectify the situation, the student used the menu option to instruct the robot to grasp the funnel. He then switched to direct control, lifted the funnel, and broke the air lock. It was observed that experiments which make demands in terms of task planning and action sequencing holds the student's interest far longer than highly automated experiments.

A demonstration task has been developed to illustrate the perceived role of a programmable robotic workstation in a vocational rehabilitation environment where the robot supplements the physical and cognitive skills of a disabled worker. The demonstration task involves the construction and sorting of simple assemblies using the robot system under voice control. Other tasks are likely to include visual inspection along the lines proposed by a research group at Delft University where the operator provides the visual and decision information while the robot provides the manipulative skills.

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23.2

CONSUMER CRITERIA FOR EVALUATING ASSISTIVE DEVICES: IMPLICATIONS FOR TECHNOLOGY TRANSFER

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ABSTRACT

This paper presents initial results of a preliminary study on the criteria used by long-term consumers of assistive technologies in evaluating their devices. The study assembled two groups of persons with physical disabilities who use a variety of assistive devices—a Panel of Consumer Experts With Mobility Impairments and a Panel of Consumer Experts With Sensory Impairments. A modified version of the three-stage Delphi method was applied to each panel separately to identify and prioritize the evaluation criteria used by panel members. In total, 17 general evaluation criteria were identified and prioritized for 11 types of assistive technologies.

INTRODUCTION

Until this time, there have been no comprehensive studies to discern the criteria that persons with disabilities use to assess their assistive devices. Consequently, designers and manufacturers of assistive devices have not been provided adequate insight on the consumer issues they should consider in developing their products. Devices that are not designed adequately to meet the needs of the disabled consumer, as defined by the consumer, are likely to cause dissatisfaction and possibly abandonment of the device [1].

To avoid such problems and the emotional frustration and economic waste associated with them, it is valuable to study the decision-making criteria used by long-term consumers of assistive devices. Through their positive and negative experiences with their devices over an extended period of time, such consumers have had an opportunity to develop normative criteria for evaluating assistive technology. Their criteria will be useful to designers and manufacturers, as well as to more recently disabled persons and large-scale purchasers of devices (such as insurers and government agencies).

METHODS

Two groups of long-term consumers of assistive devices were assembled at two separate meetings to identify and prioritize evaluation criteria. The Panel of Consumer Experts With Mobility Impairments consisted of six persons with four different disabilities, including cerebral palsy, spinal cord injury, muscular dystrophy and post-polio. The Panel of Consumer Experts With Sensory Impairments included three persons who are deaf, one person who is hard-of-hearing, and two persons who are blind. Panel members were selected for their long-term use of assistive devices and their well-developed analytical skills.

Prior to convening the panels, the researchers identified and defined a set of 12 criteria, based upon their professional and personal experiences in evaluating assistive devices. Each panel was then convened, and a modified version of the three-stage Delphi method was used to achieve a group consensus on criteria [2]. In stage one, panel members were asked to identify the criteria they would use in assessing several types of assistive technologies. Their criteria were compared to those of the researchers, and the original set of 12 criteria was modified accordingly. In stage two, panel members were then asked to rank the criteria in terms of importance for each of the technologies assessed. In stage three, they were asked to explain verbally to the group their prioritizations in stage two, and then to reprioritize the criteria taking into consideration the overall rankings of the group.

The three-stage Delphi was applied to the mobility panel at the first meeting of the study. That panel assessed five types of technology: motorized wheelchairs, typing systems, robotic arms, environmental control systems and phone systems. The Delphi was applied to the sensory panel two weeks later at the second meeting of the study. That panel was divided into two sub-groups: persons who are deaf or hard-of-hearing and persons who are blind. The hearing-impaired members assessed three types of technology: alerting systems, phone systems, and speech recognition systems. The blind members similarly assessed three types of technology: type reading systems, recording systems, and orientation systems.

RESULTS

The 12 general criteria identified and defined by the researchers prior to the panel meetings were verified by the panels during the meetings. Five additional criteria were identified by the panels during the two meetings. The 17 criteria identified are:

Affordability - the extent to which the purchase, maintenance, and/or repair of the device causes financial difficulty or hardship to the consumer.

Compatibility - the extent to which the device will interface with other devices currently and in the future.

Consumer Repairability - the extent to which the average consumer (or his or her personal assistant) can repair the device if broken, including whether special repair equipment is needed.

Dependability - the extent to which the device operates with repeatable/predictable levels of accuracy under all conditions of reasonable use.

Durability - the extent to which the device will continue to be operable for an extended period of time.

Ease of Assembly - the extent to which the consumer (or his or her personal assistant) can easily assemble the device upon receiving it, including whether it is packaged conveniently.

Effectiveness - the extent to which the functioning of the device improves the consumer's living situation, as perceived by the consumer, including whether it enhances functional capability and/or independence.

Flexibility - the extent to which the device is provided with available options from which the consumer may choose.

Learnability - the extent to which the consumer, upon initially receiving the device, can easily learn to use it and can start using it within a reasonable period of time once assembled, including whether specialized training is required.

Maintenance - the extent to which the consumer (or his or her personal assistant) can easily maintain the device to keep it operable and safe, including whether it is easy to conduct all required maintenance, cleaning, and infection control procedures.

Operability - the extent to which the device is easy to operate and responds adequately to the consumer's operative commands, including whether controls and displays are accessible and whether start-up time for each use is excessive.

Personal Acceptability - the extent to which the consumer is psychologically comfortable in using the device in public (or even in private), including whether the device is aesthetically attractive.

Physical Comfort - the extent to which the device causes physical pain or discomfort to the consumer.

Physical Security - the extent to which the device is likely to cause physical harm, including bodily injury or infection, to the consumer.

Portability - the extent to which the device can readily be operated in different locations, including whether the length of battery charge and the size and weight of the device permit physical relocation.

Securability - the extent to which the device can easily be kept within the physical control of the consumer to reduce the likelihood of theft or vandalism.

Supplier Repairability - the extent to which a local supplier or repair shop can repair the device within a reasonable period of time, including whether replacement parts are readily available and whether the manufacturer must conduct repairs.

These criteria were further operationalized through the identification of sub-criteria in stage one for each of the technologies assessed. The specific sub-criteria for all 11 types of technology assessed will be presented in a subsequent paper.

The results of the final prioritizations in stage three are presented in Table 1 below. They indicate that effectiveness, affordability, operability, and dependability are, on average, regarded as the four most important criteria for all technologies assessed. Ease of assembly is regarded as relatively unimportant across disabilities and technologies. The ratings of the other criteria depend largely on the specific technology being considered.

DISCUSSION

It must be stressed that this was a preliminary study assessing the criteria of a small number of long-term consumers of assistive devices. For purposes of this study, no attempt was made to obtain a statistically representative sample of long-term users of assistive devices in the entire disabled population. The criteria identified and prioritized, therefore, do not necessarily constitute the criteria and prioritizations of other long-term consumers of assistive devices. The study does, however, provide insight on the criteria used by two groups of consumers specifically selected for the study due to their long-term use of assistive devices and their developed analytical skills.

Therefore, despite the limitations of this study in making statistical inferences to the general population of persons with disabilities, the results provide valuable information to designers and manufacturers on the needs of two selected groups of sophisticated consumers. To the extent that future studies demonstrate that the criteria of the consumers in this study are representative of the criteria of long-term consumers of assistive devices generally, these criteria should be used to guide the design, manufacturing, and purchasing processes. Failure to consider such consumer evaluation criteria is likely to result in abandonment of devices by disabled persons, and a general failure of the process of technology transfer.

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TABLE 1. FINAL RANKINGS OF CRITERIA BY PANELS

	Mobility Technologies					*Blind Technologies*			*Deaf Technologies*			
	Wheel-Chair	*Typing System*	*Robotic Arm*	*Environ. Control*	*Phone System*	*Type Reader*	*Recording System*	*Orientat. System*	*Alert System*	*Phone System*	*Speech Recog.*	*Average Ranking*
Effectiveness	1	2	1	1	1	2	2	2	1	1	1	1.36
Affordability	4	5	4	6	6	1	1	1	2	2	2	3.09
Operability	2	1	2	2	2	5	7	10	5	3	3	3.82
Dependability	3	4	3	3	3	3	3	6	4	5	5	3.82
Portability	*	*	*	*	*	7	4	3	6	4	8	5.33
Durability	8	8	8	7	7	4	5	11	3	6	6	6.64
Compatibility	13	3	6	4	5	6	6	13	10	7	4	7.00
Flexibility	7	6	5	5	4	11	9	15	8	9	7	7.82
Ease of Maintenance	6	9	11	9	11	8	8	8	7	10	9	8.73
Securability	*	*	*	*	*	13	11	7	11	12	14	11.33
Learnability	14	7	10	11	10	9	16	14	14	11	10	11.45
Personal Accept.	5	11	7	13	9	15	15	12	13	14	13	11.55
Physical Comfort	10	13	13	14	8	12	13	9	17	8	11	11.64
Supplier repair	9	10	12	8	12	10	10	16	16	16	12	11.91
Physical security	11	15	9	10	15	17	17	4	12	13	16	12.64
Consumer repair.	12	12	14	12	13	14	12	5	15	17	15	12.82
Ease of assembly	15	14	15	15	14	16	14	17	9	15	17	14.64

* These criteria were identified by the sensory panel at the second meeting, and were not ranked by the mobility panel.

23.3 TECHNOLOGY TRANSFER AT THE REHABILITATION R&D CENTER OF THE PALO ALTO VA MEDICAL CENTER

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ABSTRACT

In 1983, recognition that the products we were developing for disabled veterans were not reaching the end user led us to propose that we contract out a study of technology transfer (TT) of our products and the roadblocks to such transfer. By coincidence, since the contract was awarded in 1985, it was during the performance of that study by the American Institutes for Research (AIR) that the Technology Transfer Act of 1986 was passed by the Congress. It was therefore possible to incorporate the altered climate and new opportunities in Government Laboratories into a final "Guidebook" to be used by investigators working in government laboratories, particularly within the VA system. It is expected that the use of this Guidebook will enhance and expedite the commercialization of products developed in our laboratory and elsewhere.

INTRODUCTION

Since the Rehabilitation R&D (RR&D) Center was established at the VA Medical Center in Palo Alto, we have been involved in the development of repair techniques and assistive devices to better the lives of disabled veterans. A large part of our mission is to get devices and techniques into the marketplace where they could be purchased or obtained or used by the disabled population that needed them. Despite the development of some 25 new products to various stages of prototyping, we were not as successful as we had hoped in accomplishing this goal, partly because of restrictive legislation and regulations, and partly because of a lack of TT and business acumen among our investigators.

Prior to the Technology Transfer Act of 1986, the life cycle of a project within our laboratory generally followed a straight line which, because of its sequential nature, involved long time constants and could easily lead to a fully developed prototype which no manufacturer would accept without a complete redesign. This situation arose because the manufacturer had no input into the initial design. This, in turn, was because there was no simple mechanism for involving a pre-selected manufacturer without the necessity of obtaining competitive bids on the final product. That situation changed substantially with the passage of the new law, which now permits branching of the project process at any point to an agreement with industry which could lead directly to a marketable product. The new law actually authorizes local Federal laboratory directors to negotiate agreements with industry which provide for income to both the laboratory and Federal employee inventors.

APPROACH

A series of meetings was held between the professional staffs of the RR&D Center of the VA and AIR. Following those meetings and agreement regarding the goals and scope of the project, an advisory committee was formed consisting of members from user groups, third party payers, manufacturers, and rehabilitation professionals.

We decided to survey manufacturers for their views of the TT process, and then to survey existing projects within the Center to determine the stage that such projects were in and the decisions that need to be made by investigators in moving any products to production. The latter survey produced the breakdown of projects shown in Figure 1. Additionally, we undertook to produce a Guidebook which could be used by investigators, by the Center Director, and by a Tech Transfer Officer to streamline and expedite the transfer of Center products, and to make it easier for the investigator to participate as an active and important player in that activity. The Guidebook was created by professional staff of the American Institutes for Research, with the close cooperation and collaboration of investigators from the RR&D Center.

METHODOLOGY

The Guidebook is titled *Facilitating the Transfer of Rehabilitation Technology: A Guide for VA Investigators, the Transfer Officer, and the Center Director*. It is organized and formatted in a unique way which is intended to make it a useful *tool* which investigators will find to be helpful in matters pertaining to the TT of any products or processes they may be developing. It does not pretend to give the reader extensive or detailed knowledge in any of the areas being addressed, but rather presents the very basic information that will help him/her to make the necessary decisions regarding

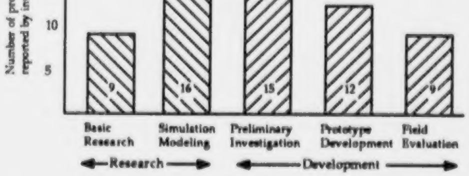

Fig. 1: Profile of RR&D Center project types as characterized by investigators

a particular project or to seek the right person or the appropriate procedure or reference when necessary.

In particular, the Guidebook is organized according to the interests of each party for whom it is written. That is, each page is keyed with a symbol at the bottom to indicate who should pay special attention to that page. Further, a separate "template" is added for each of the three expected types of readers, in addition to the Table of Contents, to show each which pages should be of most interest for his/her participation in the TT process. The book also contains a glossary of unfamiliar terms and explains the incentives for participation of the individual laboratory employee, as well as the realities of patenting, licensing, and interacting with representatives of industry.

The roles of each of the three TT participants in the laboratory (i.e., the Investigator, the Laboratory Director, and the Transfer Officer) are clearly explained, with specific examples of what activities might be undertaken by each and how he/she is expected to interact with the others. For example, under the heading "The role of the investigator", we find the following statements: "In addition to the recognition you get from working in your discipline and the challenge that is inherent in scientific inquiry, you will find great satisfaction if your actions contribute *directly* to the team effort in the Center regarding TT. The following activities should involve some level of interaction with the Transfer Officer (T), the Center Director (D), and colleagues or cooperating organizations (C)." This statement is then followed by a table showing specific investigator activities with check marks or blanks assigned to each of the above symbols.

DISCUSSION

The study conducted by AIR indicated, above all, the importance of *early* involvement of a manufacturer in developing a product intended for commercialization. This has been difficult to accomplish within the Government system of laboratories until the passage of the Technology Transfer Act. Now the mechanism is in place, but has the disadvantage that any company involved must be financially able to contribute either funds or personnel to the project without reimbursement. This is sometimes a problem in field of rehabilitation.

Since the new Guidebook produced by AIR under contract to the Palo Alto VA RR&D Center incorporates the effects of the new legislation, it is expected to be both useful and educational to investigators working in government laboratories who could and should now participate actively in TT activities. For our laboratory, those activities can now bring income both to them and their laboratory, in addition to expediting the availability of their products to the end user for whom it was intended. The previous straight-line process through which projects in our laboratory had to pass can now be branched to industrial collaboration at any stage of development, and can progress directly to a manufactured commercial product. In other government laboratories, where the research was intended for a government purpose or for educational purposes, the base of possible end users may be greatly expanded through commercialization.

In order to take full advantage of the new Guidebook discussed herein, and of the new opportunities available to government laboratories under the Technology Transfer Act of 1986, we have established in our laboratory a new Technology Transfer Group, consisting of existing professional staff with explicit personal experience in some aspects of TT. These individuals are now spending part of their time as a service group which coordinates and assists the efforts of other investigators in the TT of products developed within our Center. In addition, this group will actively pursue (or help investigators to pursue) new possible industrial collaborators, "get the word out" about our technical work, and assemble the necessary central resources needed to successfully transfer our technology to private enterprise for developing commercially available products for the use or care of disabled veterans. One of these resources is an easily accessible database of information on all of our products, including status, purpose, personnel, funding, and pertinent details. The TT Group will also assist in filing patent disclosures, will pursue the patent process with the investigator, and will act as negotiators for the Center in arriving at Cooperative R&D Agreements with industry.

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23.4

TOWARD UNIVERSAL DESIGN: A PROJECT ON THE ERGONOMICS OF DISABILITY

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ABSTRACT

Understanding the consumer is at the heart of any successful business venture. Knowing what drives a disabled person to select, purchase, and use a given product enables a manufacturer to make effective design and marketing decisions.

Manufacturers of "special" assistive products for disabled persons, as well as mainstream consumer manufacturers, are now competing for the growing market of disabled consumers. This competition is already spawning products that are more useful to both able and disabled consumers, yet less expensive than lower-production "special" products.

We believe this is a healthy trend and are supporting it through a project designed to offer current demographic and ergonomic data concerning the disabled population. This paper presents our progress to date in analyzing the results of the National Health Interview Survey and designing a framework for sharing this data with industry.

INTRODUCTION

Disabled persons represent a growing segment of the consumer population. The number of Americans with severe physical disabilities increased by more than 49% between 1970 and 1981 (Cherry, 1984). Advances in medical technology are enabling people who suffer serious illnesses or injuries to survive longer and more independently. Some of the disproportionate growth of the disabled population can also be attributed to aging. Anyone who lives long enough will become disabled. By the turn of the century, 1/3 of the U.S. population will be physically disabled, chronically ill, or over 65 years of age (Business & Health, 1988). People with disabilties are clearly among the fastest growing market segments in the world.

Fortunately, recent nationwide surveys have yielded valuable information about the demographics and ergonomics of this population (LaPlante, 1988, U.S. Bureau of the Census, 1986). Because of its coverage of all age groups of consumers and its focus on "activity limitation", the National Health Interview Survey is the most useful for this purpose. Through the NHIS, information is now available to enable businesses to formulate effective marketing strategies to disabled consumers. It is the purpose of this report to point out the demographic data that exists for use by product designers, manufacturers, and developers toward the establishment of a more "universal" approach to product design.

DISABILITY AND FUNCTIONAL LIMITATIONS

Over 70 chronic conditions are listed in the NHIS report. Each of these conditions has the potential for causing one or more functional limitations which create ergonomic differences between the disabled and non-disabled consumer. Translating the NHIS data on chronic conditions into data on functional limitations helps to form the basis for establishing an ergonomic system concerning disabled consumers. The premise for this system is that a chronic condition which causes a limitation of activity can be described in terms of some combination of specific functional limitations. Despite the variety of possible conditions, the variety of functional limitations is concise.

The following list of functional limitations was derived from similar systems published by the U.S. Department of Housing and Urban Development and the U.S. Department of Education (Mueller, 1979; Schroeder, 1979). This list is the basic vocabulary for describing the ergonomics of disabled consumers.

Working from the NHIS tables, an estimate of the number of people experiencing each functional limitation has been derived, shown below to the nearest 100K. (Complete project reports also include market segmentation by age and sex.) This offers to product planners vital information on potential market impact of design features targetted toward persons with a specific functional limitation:

Difficulty in Interpreting Information: 2.7m
Limitation of Sight: 4.5m
Total Blindness: .4m
Limitation of Hearing: 1.1m
Total Deafness: 1.7m
Limitation of Speech: 4.4m
Susceptibility to Fainting, Dizziness, Seizures: 13.3m
Incoordination: 6.5m
Limitation of Stamina: 19.2m
Limitation of Head Movement: 12.7m
Limitation of Sensation: 4.9m
Difficulty in Lifting and Reaching with Arms: 12.3m
Difficulty in Handling and Fingering: 10.3m
Inability to Use Upper Extremities: .3m
Difficulty in Sitting: 13.1m
Difficulty in Using Lower Extremities: 18.0m
Poor Balance: 11.2m

NOTE: Since some individuals experience more than one limitation, simply totalling the above estimates would result in multiple counting of these people.

DISABILITY AND AGE

"Except for small decreases at ages 18-24 and a sizable decrease at ages 70-74 (probably due to a redefinition of major life activities at this age, as described above), the percentage of the population with activity limitation increases with age" (LaPlante, 1988).

Despite the traditional social, political, and economic differences keeping the disabled and aging populations apart, similarities in functional characteristics are unavoidable. Therefore, products usable by disabled consumers will generally find a market among a portion of the aging population, especially if those products do not carry with them a stigma of handicappism. (This "transgenerational" approach to product design and marketing is one technique that product manufacturers are using to increase sales of both mainstream and "special" products.)

DISABILITY AND BUYING POWER

"Disability is clearly inversely related to family income"(LaPlante, 1988). Families with disabled members often face challenges in meeting ongoing medical expenses, as well more ordinary needs, on a limited budget. Since products intended exclusively for disabled consumers tend to be more expensive than mainstream products, disabled people are looking more and more to mainstream products that can meet their needs at a reduced cost.

For example, persons lacking the coordination or strength to dial or key in a 7- or 10-digit telephone number, especially in an emergency, have historically turned to environmental control and emergency call systems costing up to $3000. Recent integration of memory-dial and voice recognition features into conventional telephones now make it possible for many manually-limited persons to use these products instead. Most of these products can be purchased for under $200 and serviced through regular dealer networks.

Products such as telephones, environmental control systems, and emergency call devices may well be covered under insurance plans in the near future. This will make these products accessible even to those persons currently unable to afford them through personal finances. Obviously, those products which best serve the consumers' needs will reach the broadest market.

CONCLUSION

For a number of reasons, disabled people are an increasingly important market to product manufacturers. Making products more useful for them results in better products for all consumers.

The next step toward this end is to provide specific ergonomic guidelines for consumers with each of the above functional limitations.

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23.5

SDIO TECHNOLOGY TRANSFER: LIGHTWEIGHT COMPOSITE BRACE

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ABSTRACT

SDIO composite materials were investigated to demonstrate feasibility of fabricating a prototype demonstration orthotic brace much lighter than steel designs.

A simulated carbon fiber composite material full leg brace was constructed and tested. The 173 gram composite test part withstood a 401 lb load with a maximum vertical deflection of 0.175 in. In comparison, a 318 gram steel upright withstood 207 lbs with 0.425 in. vertical deflection.

A full leg set of carbon fiber composite braces has been fabricated for use as a demonstrator prototype for weight comparisons and further development, testing and evaluation.

INTRODUCTION

This project began in response to an expressed need for development of lighter braces.[1]

In 1988, Crookes *et. al.*[2] reported on the use of selective orientation of composite materials Kevlar 49 and vinylester resin to replace polypropylene in an ankle-foot orthosis with a weight reduction of over 70%.
In the current study, carbon fiber reinforced composite materials were investigated to demonstrate the feasibility of using composite materials to fabricate a prototype proof of concept demonstration orthotic brace which is much lighter than steel designs. The project consisted of analysis, design and fabrication of a lightweight orthotic brace using composite materials which were developed or used in SDIO programs.

METHODS

Preliminary analysis was undertaken to obtain first order results for the orthosis design: elliptical cross section upright core - first order stiffness; finite element beam model was completed; Patran upright model elastic modulus = 24 Msi. Hercules IM6 carbon fiber (E=42 Msi, Uts = 600 Ksi) and U.S. Polymeric resin system (250°F cure) were the materials used.

A full scale simulated right, medial, digital upright, band and footplate section was constructed to test the fabrication technique and processing parameters in preparation for fabrication of a full scale brace. The simulated section was also used to provide mechanical test verification of the initial analysis.

Compression and load vs. deflection tests were completed on the simulated lower leg composite brace and a steel upright section (which was bent to match the composite lay-up contour).

Full leg composite brace fabrication was completed as follows: 1. Obtained casts of a paraplegic volunteer's legs. 2. Aligned spacer strips for uprights and bands. 3. Prepared foot sole with release tape. 4. Formed upright and band cores to cast contour. 5. Made layup of composite uprights/joints, bands, and footplate. 6. Prepared for processing (release cloth, bleeder fabric and vacuum bag). 7. Processed final part. 8. Completed minor trim and application of pads.

RESULTS

Preliminary finite element analysis predicted composite upright to be 40% stiffer than steel and two times stronger.

The 173 gram composite simulated lower leg brace withstood a 401 pound load with a maximum vertical deflection of 0.175 in. By comparison, the 318 gram steel upright withstood 207 pounds with a maximum 0.425 in. vertical deflection.

A full leg set of braces has been fabricated with a reduction in weight of over 66% in comparison with the original steel brace sample. (See Figure 1.)

DISCUSSION

Axelson, et al[3], have pointed out the importance of standing in spinal injury management and the need for devices to assist in standing.

While this project was focused on the development of a lightweight orthotic brace for possible assistance in standing of spinal cord injured persons, it must be stressed that this was a preliminary project to fabricate one prototype and has not been evaluated for applicability to a broader population.

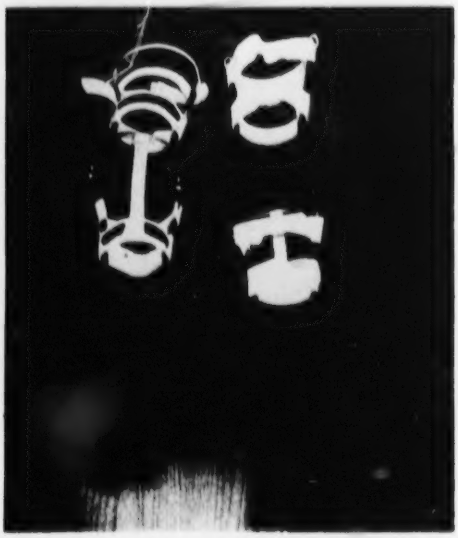

Figure 1. Lightweight carbon fiber composite brace demonstrator.

It is possible, however, that this lighter weight composite technology could be used to help overcome some of the human fatigue problems associated with the weight of reciprocating gait orthosis (RGO) braced external functional electrical stimulation (FES) walking systems.

ACKNOWLEDGEMENTS

The efforts of the following persons who contributed to this project are greatly appreciated. Industry support was received by Mr. Richard Fite of Orthomedic, Inc. who fabricated the positive cast and provided orthotic expertise. Mr. Scott Hornbeck of U.S. Manufacturing supplied metal joints. Mr. Kyle Scott of NASCOTT, Washington, D.C. assisted with casting of subject. This project was funded by Sparta, Inc., Laguna Hills, CA and the National Rehabilitation Hospital, Washington, D.C.

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23.6

IMPLEMENTATION AND FOLLOW-UP OF REHABILITATION TECHNOLOGY

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ABSTRACT

The purpose of this study is to improve the transfer of rehabilitation technology to people with physical limitations by developing, testing and promulgating a system for successful implementation and follow-up. The initial phase of this three-phase study is being conducted at Children's Hospital at Stanford, Rehabilitation Engineering Center. During the second phase the follow-up system will be implemented at four centers within California. The final stage will consist of national dissemination. The long-range goals of the follow-up system are to 1) increase the quality of the products; 2) increase user satisfaction; and 3) initiate a feedback loop to product manufacturers.

BACKGROUND

In the rehabilitation technology field at the present time, there does not exist a recognized, comprehensive, or even minimally adequate system for implementation and follow-up of technological devices once they are built and delivered to disabled users. It is assumed that "no news is good news", but that can also mean that the device is "sitting in the closet".

Prosthetics and orthotics traditionally have been reimbursed by payment for specific devices and not for services. For example, a fee schedule which covers payment of a lower-limb prosthesis includes the evaluation/assessment at the beginning and implementation/follow-up after provision.

In the newer, broader field of rehabilitation technology, the need for and payment of the assessment services and implementation/follow-up services need to be considered in the cost of providing the device. For example, a $100 device may require $500 of evaluation/assessment and implementation/follow-up to enable its successful use. As more rehabilitation technology has become available, the critical areas of the "match" of the device to client, and the follow-up/training in use require time and expertise on the provider's part.

STATE OF THE ART

A study in 1980 (REC, CH@S) noted that a review of the literature showed little clinical evaluation of assistive technology. The need for evaluation material was documented, including cost and time factors in device life span and use. The impression that provision of assistive technology must satisfy technical performance requirements as well as lifestyle, vocational and physical environment needs, and user preferences was validated by the study. Recommendations were made which included documentation of success in these areas and the "routine follow-up should be provider initiated, at regular intervals, and the cost of follow-up should be included in the initial cost of the device" (Kohn, et al, 1983).

No new studies on evaluation which can be incorporated into the delivery system have been reported in the literature. The crucial area of evaluation of technology by the user remains unexplored in a systematic manner which would be comparable across centers to allow for data review and action. Providers must be "pro-active" in initiating contact with users following delivery of technological aids, and they should have the methodology available to incorporate follow-up information into individual records for easy retrieval.

OBJECTIVES

The overall goal of this project is to improve the transfer of rehabilitation technology to people with physical limitations by developing, testing, and promulgating a system for successful implementation and follow-up.

The specific objectives are to:

1. Develop and test an implementation and follow-up system at Children's Hospital at Stanford (CH@S) REC client services program.

2. Refine and test the implementation and follow-up system at four other

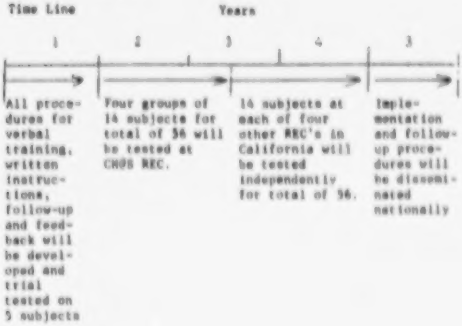
REC's in California with client services programs.

3. Promulgate the implementation and follow-up system nationally.

The hypothesis is that a well-thought-out implementation and follow-up system incorporated into the rehabilitation technology provision process will a) increase the overall acceptance and use of devices; b) increase user satisfaction; and c) initiate a feedback loop to product manufacturers.

METHODOLOGY

Services to be included in the implementation and follow-up process are: 1) verbal training in use at time of delivery; 2) written instructions and information; 3) follow-up after use; and 4) feedback to manufacturers and researchers.


Time Line
Years
1
2
3
4
3
All procedures for verbal training, written instructions, follow-up and feedback will be developed and trial tested on 5 subjects
Four groups of 14 subjects for total of 56 will be tested at CHOS REC.
14 subjects at each of four other REC's in California will be tested independently for total of 56.
Implementation and follow-up procedures will be disseminated nationally

PRESENT STATUS

A two-part mini-study was conducted at the Stanford REC to determine: 1) status of medical record charts from 1983-1987 regarding follow-up; and 2) the type and amount of follow-up currently used in the delivery sessions. In part one, 72 charts were reviewed where 92 products were delivered. Eighty-five follow-up visits were recorded from a total of 37 clients. Findings indicate that 56% had never been seen for a follow-up visit. Only 21% of the total follow-up visits were iniated or scheduled by the REC staff. Finally, 97% of the charts did not include a minimally adequate follow-up system.

Part two of the study focused on any verbal, written and general follow-up directions given to clients during the delivery session. Out of the 15 sessions observed, 51% of directions regarding follow-up were not given. Since a 100% positive response would indicate an efficient follow-up system, it can be concluded that the current delivery sessions contain less than half of the optimal amount of follow-up information.

IMPACT

The immediate impact of this project- to develop and test a system for implementation/follow-up of the transfer of rehabilitation technology is primarily a local one to the five centers involved. However, the methodology to be developed, with demonstration of successful use, could have a profound influence on rehabilitation technology services and upon the disabled people who receive devices.

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COMMUNITY SERVICES: THE SECOND YEAR

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ABSTRACT

Community Services, a community agency which provides independence through education, therapy, and technology, has been in existence for two years in southern Illinois and Missouri. This paper discusses the developments and expenses of years one and two, the establishment of specialized interagency programs, and some of the problems of private practice.

INTRODUCTION

In June 1987 Community Services, a private practice providing independence through education, therapy, and technology, evolved from a university based program that provided pediatric occupational therapy services to community agencies (1). Community Pediatrics, a university based program that was once under federal grant funding, underwent several administrative changes, one of which dismantled most of the program.

YEAR ONE

In the first year eight community agencies requested services (2). Direct services were requested by two special education districts serving students aged 3-21, a private school serving students aged 3-21 with severe and profound disabilities, and a birth to three year homebound program. Requesting computer evaluation and training on one year contracts were three agencies. The Program in Occupational Therapy at Washington University retained teaching services for two courses.

Startup expenses for the first year included malpractice insurance, printing costs for letterhead, accountant's fee to set up bookkeeping practices, and computer equipment. Because the technology center used through Washington University was no longer available, a core group of computer equipment and adaptations for special needs was needed. Existing computers included Tandy 100 with 256K, NEC Starlet with 128K, and Commodores 64 and VIC 20. A computer system, a Tandy SX 1000 with Trackstar 128, allowing MS DOS and Apple software compatibility; adaptive equipment, a Unicorn expanded membrane keyboard and one keyboard emulator, DADA's PC Serial AID, were purchased in the first year. Two other emulators, the MOD Keyboard module and cables for a MS DOS computer system used with the Commodore VIC 20 and the Adaptive Firmware Card for the Apple IIe system, were borrowed for evaluation purposes. Switches used with the three emulators were made with parts purchased from Radio Shack.

YEAR TWO

The four agencies with contracts for direct services renewed contracts for the second year. The hourly rates and expense reimbursement remained the same, but two additional items were requested: a long distance telephone calling card for phone calls pertaining to agency business and the purchase of the standardized test forms used for individuals within the agency.

A new contract for direct services was signed with a residential adult intermediate care facility. As a requirement of placement, the residents spend eight hours of the day away from the facility in school, adult treatment programs, workshops, and supportive employment. The consultation requested included both residential and day staff. A contract for consultation services was signed with a corporation consisting of two healthcare catalog companies. Services for this contract include product evaluation and consultation to specific areas of the product line. With an administrative change in Washington University's Program in Occupational Therapy teaching services were no longer needed; however, the Occupational Therapy School in University of Missouri at Columbia contracted for teaching.

In the second year monies were allocated for standardized tests. The following were purchased: Test of Visual Motor Skills; Test of Visual Perceptual Skills; Bruininks Oseretsky Test of Motor Proficiency; Peabody Developmental Motor Scales; Test of Auditory Perceptual Skills; Quick Neurological Screening Test; and Scales of Independent Behavior. The standardized tests add to the validity of evaluation, recommendations, and report writing.

Additional money was spent on continuing education opportunities: computer applications, seating and mobility, and augmentative communication conferences, workshops, and symposia. The first seating and mobility certification course offered by the University of Tennessee Rehabilitation Engineering Program was successfully completed in June 1988.

SPECIALIZED INTERAGENCY PROGRAMS

In each of these contracts a good team relationship was developed with the physical therapists and speech pathologists employed by the agencies. As cooperative ventures between Community Services and each agency, three clinical programs were instituted: Seating and Mobility, Augmentative Communication, and Computer Applications. These clinics utilize a team approach with a social worker seeking payment sources and the parents and teachers involved as well as the clinicians. Evaluating, recommending, and fitting of devices occurs on site, thus eliminating many of the problems associated with hospital based programs. In September 1988 Community Services received on long term loan an EvalPac with RealVoice for research and evaluation purposes from Adaptive Communication Systems, 345 Hookstown Grade Road, Clinton, PA 15026, (412) 264-2288.

PROBLEMS

Because of staffing difficulties, the steady growth of the Community Services has become the largest problem. At this time the only opportunities for expansion will come with additional personnel. Viable contracts have been politely refused because of the lack of manpower. The determination of time needed to train new personnel has been a factor, but will be addressed during the training of occupational therapy clinical students affiliated with University of Missouri at Columbia.

ACKNOWLEDGEMENTS

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24.2 UCP'S PROJECT INCENTIVE "EXPANDING THE USE OF ASSISTIVE TECHNOLOGY"

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ABSTRACT

Assistive technology services and devices can be used effectively to dramatically improve the suitability of worksites and increase a persons' productivity and efficiency. UCPA's Project Incentive employment program, has developed solutions to problems, primarily low tech solutions, which have provided the essential edge for people with physical disabilities to become employed and to work along side co-workers to the greatest of their capacity.

BACKGROUND

The project incorporates the concept of supported employment. There are many definitions of supported employment, but basically it is paid work in a regular setting where the person with disabilities works and interacts with co-workers and performs the usual tasks of the worksite. The worksite may be modified to accommodate this employee and ongoing support the person needs to perform the job is provided.

INTRODUCTION

In October of 1988, UCPA began Project Incentive to establish the effectiveness of involving rehabilitation technologist with the employee who is disabled and the job trainers, who are providing on the job training. During the past 13 months, over 30 accommodations have been developed and installed for over a dozen people. All of these have been low tech solutions to mostly everyday problems which have helped people with significant physical disabilities to work more efficiently and productively on their jobs. We are currently working with three UCPA affiliates in two states.

Several materials will be available at the end of the project in October 1989 to describe the methods used and to encourage replication of this model. These will include a Business Reference File for information on contacting businesses, an Implementation Guide to the accommodations used during the project, two different pamphlets describing the rehabilitation technology process to employers and to job trainers and developers, and a booklet discussing the SSI work incentives for those people who would like to work and are worried about the effect that will have on their SSI benefits.

In addition, a rehabilitation technologist apprentice program will develop materials to assist an agency to identify and outfit staff with the basic skills and creativity to work as rehabilitation technologists. An inventory of a tool box with necessary tools for job site evaluations and simple modifications will be included.

METHODS

Rehabilitation technologists can become involved with an employee who is disabled as early as specific problems or questions arise regarding the work environment. Non-work problems which affect any work the person did, such as wheelchair positioning or personal care needs can also initiate rehabilitation technology services.

In early contacts with the employer, the job trainer, who provides the support on the job, or the rehabilitation technologist apprentice can begin the job site evaluation by observing the applicant in various settings on the job. Video taping and photography, where acceptable to the

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employer, can be used to communicate with the rehabilitation technologist or the apprentice, and can provide much information without additional intrusion into the workplace and without unnecessary expense of the rehabilitation technologist's time.

Project Incentive staff has, by example and development of the apprentice program, worked to teach supported employment personnel how to evaluate job sites and solve problems. Solutions that work are most often low tech solutions which help adapt work settings to employees with physical disabilities and make the setting safer for all employees by correcting previously ignored problems.

It is important to remember not to overshoot solutions. We demonstrate, by example, that others can solve accommodation problems without the need for unlimited resources. Solutions are most often simple and practical, demonstrating that technology is not justified by its complexity but by its suitability. For example, the Project has implemented 32 accommodations at work sites with an average cost of $44.52 per accommodation. The accommodations are simple and direct yet they solve significant problems which impede the efficient and effective functioning of an employee with physical disabilities.

Another critical focus of the Project is to educate people on the work incentives in the law for people receiving SSI benefits. The law is now more of an incentive for people to work because it is possible to work and continue to receive part or all of their benefits and their medicaid coverage.

Another provision of the law encourages people to develop plans for their professional development and purchase of specialized equipment. This is called a PASS, or Plan for Achieving Self Support. Money to pay for these plans may be sheltered from a person's salary prior to determination of their benefits. These provisions provide the incentives many people need to consider work and help to remove the fear of loosing their benefits.

Project Incentive has established the effectiveness of rehabilitation technologist working closely with people who have physical disabilities and job trainers to provide low tech solutions to work problems.

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24.3

Rehabilitation Engineering in Focus - The Hong Kong Perspective

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ABSTRACT

A brief account of the development of a broad-based rehabilitation programme is presented together with an overview of current service provision in Hong Kong. The coordination of activities of the major providers of information, aids and technical services is briefly discussed. A more detailed account is given of the new Rehabilitation Engineering Centre and its current and future commitments are reviewed.

INTRODUCTION

Hong Kong has entered what has been termed a "decade of challenge" as it heads from 140 years of colonial rule towards the status of a Special Administrative Region of the World's most populous nation. In the first one hundred years, Hong Kong grew from "a barren rock with hardly a house upon it" to a territory with a population of half a million - in the last 40 years, as a haven for 'refugees' from several neighbouring countries, its population has increased ten-fold and it now boasts the World's most densely populated urban area.

It currently enjoys a buoyant economy under 'laissez-faire' government and, although it cannot claim to be a 'welfare state' very significant strides have been made towards socialised 'medicine' and to improving social welfare, and rehabilitation in particular. The latter is achieved through a unique blend of government provision and the cohesive action of the 'voluntary sector' which enjoys substantial government subvention. This sector, comprising some 200 separate agencies, is coordinated by the Council of Social Service which itself has been a principal agent of innovation and initiation. The Rehabilitation Division of the Council of Social Services and the Government's Commissioner for Rehabilitation now plan and work together most effectively.

In the mid 1980's it was recognised that the exsiting rehabilitation engineering services were rather limited and uncoordinated and the concept of establishing a centre dedicated to rehabilitation engineering was proposed. The Royal Hong Kong Jockey Club made a donation which enabled the Hong Kong Polytechnic to establish a rehabilitation engineering centre as a Department in 1987. This generous donation provides for buildings and core funding into the 21st century.

SERVICES PROVISION

In such a hybrid system, the divisions of responsibilities are not immediately clear and a person with disability can receive technology-related services from a number of providers.

Technical Aids, Buildings and Transportation In the early 1980's two Rehabaid centres were established by the Society for Rehabilitation (one specifically for children), and staffed primarily by occupational therapists who act to provide information on sources of local and imported aids and appliances for individuals and health care professionals. Products are on display and are used in client assessment either in-house or of short-term loan. An Environmental Advisory Service is now established within the Society for Rehabilitation and is directed by an architect. The Society has also initiated a Rehabus transport service which is well-established but rapidly expanding to meet an increasing demand.

On the manufacturing and device provision front, there are several agencies which cater for different aspects of local demand. The Association of Engineering and Medical Volunteer Services is funded primarily by voluntary subscriptions and donations. This association comprises, in the main, volunteers who design and manufacture aids and produce software for use by people with diabilities. It has a combined headquarters/workshop with some full-time administrative and technical staff. Much of the engineering design and production is actual undertaken by the Industrial (training) Centre at the Hong Kong Polytechnic, which is a major manufacturing resource with its own specialist team of workers on 'Equipment for the Disabled'. A Technical Aids Resource Centre, run by the Government department responsible for technical training, provides information on and manufactures device which are directly related to the formal employment of those who are disabled. Many disability-related agencies provide aids for the use of their clients and, on occasion, provide a wider service. For example, the Spastics Association is involved in providing maintenance for manual wheelchairs in one of its sheltered workshops and is currently offering a seating service for problem cases involving extensive deformity.

JOCKEY CLUB REHABILITATION ENGINEERING CENTRE

The Centre is an integral part of the Hong Kong Polytechnic which itself is the largest of the Territory's six tertiary educational institutes, situated in the heart of the urban area. Currently the Centre has a technical staff of four engineers, coming from North America and Europe and all possessing qualifications in rehabilitation/biomedical engineering, and 4 technicians. A librarian manages a small dedicated rehabilitation information centre and administrative support is provided by administrative assistant, PS, clerk and messenger. A purpose-designed building is currently being constructed as part of a major Polytechnic development. This will accommodate a computer/design room, project development and testing facilities, mechanical and electronic workshops, an information centre, conference/product display area and offices. Care has been taken not to duplicate the extensive laboratory and workshop facilities which currently exist in the Polytechnic.

Service The Centre encourages enquiries, request and referrals from professional associated with disabled people as well as from the concerned public. Current services include:-

- Design and construction of aids
- Modification and adaptation of commercial aids
- Consultation on technical aids
- Evaluation and testing of aids to prescribed standards
- Consultation on engineering aspects of rehabilitation
- Development of apparatus and instruments for research in rehabilitation
- Organisation of workshops on construction of simple aids, toy adaptation, and technical aids
- Operation of computer-based rehabilitation information services
- Involvement in operation of a rehabilitation information centre which is open to all

Research and Development Continuous research and development is required to seek new solutions as well as improve upon existing solutions for problems in rehabilitation. Current research projects of the Centre include:-

- Environmental control systems and other microprocessor based controllers
- Seating and pressure relief
- Prostheses and orthoses
- Devices for spine and fracture rehabilitation
- Physiotherapeutic techniques for joint rehabilitation, etc.

Many of these highly interdisciplinary activities are carried out in collaboration with other local and regional and international tertiary educational establishments, as well as other departments within the Hong Kong Polytechnic.

To stimulate local research, the Centre organizes meetings, seminars and lectures involving both local and overseas professionals in the rehabilitation field.

SUMMARY

The Jockey Club Rehabilitation Engineering Centre is peculiar only in so far that it is to cater to the special need of Hong Kong, for example, its extremely high population density and congested living environment, and in the nature of its establishment. With a service commitment to be realised today, the challenge of conducting and fostering multi-disciplinary research and developing training and educational programmes, and its coordinating role, there is a fear of being 'all things and all men'. Being based strategically in both geographical and temporal terms, there is also a significant international role for the Centre to play. Information exchange and communication in general are key issues in promoting collaboration and in optimising resources and to this and information technology must be fully. It is essential that a pooling resources, both human and material, be achieved in this essential mutli-disciplinary area of endeavour in which there is clearly so much innate good will.

The Development of a Rehabilitation Technology Resource Center

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Abstract

This paper will provide an overview of the development of the mobile workshops through United Cerebral Palsy Associations of New Jersey, Rehabilitation Technology Services. Information on funding, staffing, and materials will be addressed. In addition, the statewide need to have a centralized location where individuals have the opportunity to have "hand-on experience" with assistive technology devices which lead to the development of the Rehabilitation Technology Resource Center.

Background

In the summer of 1986, United Cerebral Palsy Associations of New Jersey began providing Rehabilitation Technology Services (RTS) through a contract with the New Jersey Department of Human Services, Division of Developmental Disabilities (DDD)(1). This program utilizes mobile workshops as a tool to provide services in homes, rehabilitation centers, and jobsites. Most of the initial months of the program were spent providing presentations on how technology can assist individuals with disabilities. These informational sessions were conducted for rehabilitation centers, consumer and parent groups, college and university students.

The RTS presentations on technology include equipment/device demonstrations of adapted toys, seating and positioning systems, power and manual wheelchairs, augmentative communication aids, environmental controls, activities of daily living aids, jobsite adaptations. Despite the volume of materials brought to these presentations there are still many items which can not be demonstrated. Computers react poorly to long and frequent road trips. The size of the vans precluded bringing many different types of wheelchairs.

Many questions regarding technology are brought up and discussed during these presentations. Two of the most often asked are, "How can we try-out the equipment discussed during the demonstration? " and, "Where can we go to see more examples of this equipment? ".

The answer to the first question of "trying out" equipment, might be to contact a local durable medical equipment (DME) dealer. The limitations with a local dealer are that they usually vend equipment from a small number of manufactures. The equipment they are able to demonstrate will be limited to the companies they do business with. The typical approach to this problem is to find someone who has the device and convince them to let you try it. This solution has some obvious drawbacks when the equipment is newly on the market.

As to the question of where one goes to see more assistive devices the first answer is usually the annual RESNA conference or the National Home Health Care Exhibition. However these conferences only occur annually and are not usually local to(New Jersey).

Rehabilitation Technology Resource Center

In order to respond to the need to have a central location where individuals could "try out" and "work with" various assistive devices, UCPA/NJ set forth to develop a center that would compliment the services that were already being provided through RTS.

During the planning and development stages of the center much attention was given to the statewide need to develop the knowledge of consumers, parents, rehabilitation professionals and others of assistive technology that is available to enhance the lives of individuals with disabilities. As a result of the planning process, the concept of the Rehabilitation Technology Resource Center (RTRC) materialized. It was clear that the goal of the RTRC would be to increase the access to appropriate, available assistive technology for people with disabilities, their families, and rehabilitation professionals in New Jersey. By providing access to information about assistive technology options and ensuring the appropriateness of particular devices for consumers, it is possible for children and adults with disabilities to lead independent, productive lives at home, school, work and in the community.

Through the development of the RTRC combined with the already existing services of RTS, UCPA/NJ anticipants that the number of individuals statewide that will be able to receive services will double. It is projected that an additional 2,000 individuals will be served this year through the RTRC. In addition to the center based services, RTRC will utilize the mobile workshops to maximize the outreach to the rural parts of New Jersey and also provide services to individuals who are unable to travel to the RTRC.

The RTRC will provide consumers, their families, and rehabilitation professionals with the opportunity to receive:

* hands-on experience with various types of assistive technology devices.

* information on where to acquire devices and cost.

* information on funding alternatives.

* assistance in adapting devices to meet individual needs.

* training and demonstration sessions of assistive technology.

* short term loan of devices to determine appropriateness.

In addition, the RTRC will offer training sessions that are conducted by the various manufacturers.

The RTRC's physical structure was designed based on 5000 square feet and the clear need for displaying the various assistive technology devices and ensuring that the center is totally accessible. The space leant itself to developing a large demonstration and seminar areas and 7 offices. Manufacturers have been contacted and will continue to be contacted to arrange for long term loan arrangements of their products.

Training and demonstration sessions will continue to be scheduled through a quarterly calendar of events. The calendar is then mailed statewide to consumers, parents, and rehabilitation professional.

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PROCEDURE TO IMPLEMENT A REHABILITATION TECHNOLOGY SERVICE DELIVERY PROGRAM

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INTRODUCTION

Rehabilitation engineering and technology service delivery programs are presently emerging in a variety of clinical settings. Recent federal law approval concerning the provision of rehabilitation technology will probably expand the network of rehabilitation technology service providers. However, the number of existing publications on implementing a reimbursable rehabilitation technology service delivery programs is very limited (1). The purpose of this paper is to present the procedure required to implement a rehabilitation technology service delivery program within a rehabilitation clinic or hospital, when access to a rehabilitation engineer is limited or not available.

PROCEDURE

The following procedure is based on a rehabilitation engineering service delivery program and clinical model developed at Good Shepherd Rehabilitation Hospital (2). The following outline and description is a summary of the procedure used to implement the service delivery program.

1. Identify therapy personnel.
Identify a group of therapists (O.T., P.T., and S.T.) which are presently responsible for providing recommendations for rehabilitation technology. If this function is performed elsewhere (i.e. durable medical equipment vendors), identify a group of therapists interested in developing expertise in providing rehabilitation technology services. According to the clinical model (2), this group of therapists is identified as the Technical Aids Recommendation Team. A team coordinator should also be identified.

2. Define clinical areas of expertise or interest.
According to the clinical model (2), each therapist should define her/his area of expertise by diagnosis (cva, spinal cord, pediatrics, general rehab, etc.). In many cases, therapist in charge of the specialized clinics (M.D., M.S., C.V.A., Amputee, etc.) would also be interested in developing expertise in recommending assistive devices appropriate for their diagnostic group.

3. Define groups of assistive devices with which each member of the team is "expert" in recommending, or is interested in developing an expertise in the process of recommendation.
According to the clinical model (2) each team member will be responsible for the recommendation of a specific category of assistive devices. This will facilitate the learning process for the responsible therapist and will also facilitate learning of the use and application of new devices within each area of expertise.

4. Establish a patient/services flow chart.
The purpose of the flow chart is to organize the services of the team in a clinically logical sequence of evaluations. For the client, the flow chart provides an indication of the services that will be provided. A flow chart is recommended in the description of the clinical model (2), however, the services and their sequence should be adapted to the specific needs and populations of the rehabilitation hospital or clinic implementing the provision of rehabilitation technology service delivery program.

5. Define a referral procedure.
Referral procedures should be adopted depending on the existing services and procedures already in place in the hospital or clinic. Experience has shown that earlier referrals result in better and more thorough recommendations.

6. Define a billing procedure.
Billing procedures vary greatly according to the billing methods of the institutions. A billing procedure compatible with the existing therapy department billing procedures should be followed.

7. Develop the evaluation forms and the final report format.
Use of standardized forms will facilitate the evaluation process and will facilitate communication between the team members. A consistent final report format would facilitate ordering and payment of the recommended devices.

8. Establish a technical aids library.
The content and magnitude of catalogs and brochures of commercially available

technical aids should be as extensive as possible, with concentrations on the populations attended and services offered. National data bases should be accessible (i.e. NARIC, ABLEDATA). Specialized information services should also be accessed (i.e. Apple and IBM special need libraries).

Members of the Technical Aids Recommendation Team should have knowledge of the available product catalogs existing in the library.

9. Identify rehabilitation engineering consulting services.
Dependent on the population served by each facility, the number of patients that will require rehabilitation engineering services will vary greatly. Some hospitals may have rehabilitation engineering departments, others might use external consulting firms directly or through other agencies (i.e. O.V.R.). Nevertheless, it is important to establish contract agreements with the engineering firms prior to providing client services.

The existing limited numbers of rehabilitation engineers, should not prevent any rehabilitation facility from providing a rehabilitation technology service delivery program. It should be noted, however, that implementing a rehabilitation technology service delivery program without access to a rehabilitation engineer will limit the services possible, especially to the severely disabled. Most probably, the limitations on the service will be imposed by the availability and adaptability of commercially available devices and the ability of the team members to perform simple equipment modifications.

10. Identify other rehabilitation agencies that provide rehabilitation technology service delivery services.
Identify those agencies in your geographic area that offer services that your team cannot provide. Exchange information with these agencies on the services that your facility provides.

11. Identify durable medical equipment vendors in your area.
Identify local rehabilitation technology vendors in your area and establish a working relationship with them to provide timely and adequate service. Establish personal contacts with their representatives. Obtain full catalogs of the brands of products they distribute.

12. Initiate a technical aids demonstration laboratory.
The demonstration laboratory can be equipped according to the existing monetary resources. A basic group of devices should be available before initiating the service. Other equipment should be added to the demonstration laboratory as the services and the clientele increase. Devices for the laboratory should include those needed to perform the basic evaluations for the services established in step 3. Rehabilitation engineers should be consulted to determine the primary equipment needs, subsequent acquisitions, and design modifications.

13. Develop a marketing strategy.
Contact local physicians, therapy services, rehabilitation agencies, and, durable medical equipment vendors; provide them with information about the rehabilitation technology service delivery program.

14. Begin providing services.

RESULTS

The procedure described above was used to implement a service delivery program at Good Shepherd Rehabilitation Hospital. Implementation of the service delivery program using this procedure resulted in appropriate equipment recommendations and prescriptions, increased rate of reimbursement for assistive devices, and decreased rate of abandonment of equipment. This model of service delivery also facilitates the evaluation and recommendation procedure, facilitates training of therapy staff, and provides the client with the opportunity to try devices before purchasing.

CONCLUSION

Following the procedure outline here facilitates the implementation of a rehabilitation technology service delivery program in a rehabilitation hospital or clinic.

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24.6

REHABILITATION TECHNOLOGY SERVICE DELIVERY UTILIZING A MOBILE SYSTEM - THE KANSAS MODEL

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ABSTRACT

Delivery of rehabilitation technology services has been a major effort of members of the staff at the Rehabilitation Engineering Center in Wichita, Kansas, since 1980. Much of the effort has been in locations other than Wichita, and particularly, in locations throughout the state of Kansas. The Kansas Division of Rehabilitation Services funded the development of a mobile shop to facilitate delivery of services remote from the Wichita home base. While other states and agencies have been forerunners of the mobile delivery idea, the system developed for use in Kansas and the scheme for delivering services is a first of its kind. This paper presents the equipment that was assembled and briefly describes the method of services delivery.

EQUIPMENT

The system that was assembled consists of a 32 feet long "gooseneck" trailer coupled to a one-ton crew cab pikup truck having dual rear wheels. See Figure 1 for an external view. Equipment contained within the trailer provides metal-working and wood-working capabilities; and consists of a lathe, mill, drill press, band saw, arbor press, three kinds of sanders/grinders, vises, table saw, air compressor, gas bottles and torches, a TIG welder, and a 12,500 watts diesel-powered electric generator to provide for setup of the "shop" at virtually any location.

The trailer/pickup combination was chosen to permit use of the pickup separate from the shop when the shop is in operation at a site. Figure 2 shows a rear quarter view.

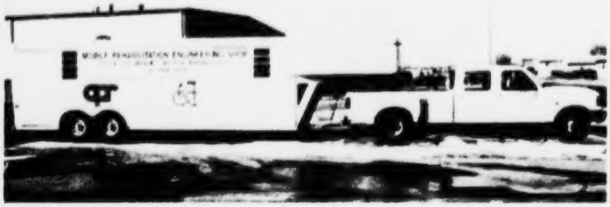
Figure 1
External View

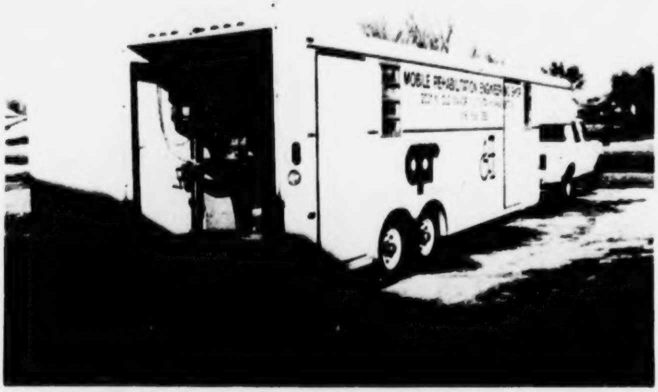
Figure 2
Rear Quarter View

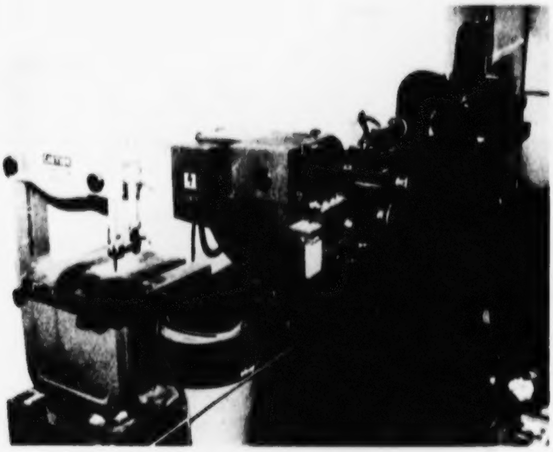

Figure 3
Interior View - Right Side

Figures 3 and 4 show interior views of the trailer and shop equipment. Space limitations prevent inclusion of a figure show-the generator and welder, both of which are located on the front shelf of the trailer.

PROCEDURES

Five months time was expended in the assembly of the unit. The Kansas Division of Rehabilitation Services is funding the project and services are provided without cost to clients of KRS. There are 31 regional offices housing rehabilitation counselors in the state. These offices are visited on a "trap-line" basis spending two days at each location. Fabrication of devices and provision of consultation is provided as time permits at each location. One complete circuit of offices has occurred to date. Fifty-nine clients were served during that time. Two additional circuits will be completed using the present format. It is then anticipated that the unit will operate on an "on call" basis.

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The authors wish to thank the Kansas Division of Rehabilitation Services for funding this project and for providing the clients to whom it is a privilege to be of service.

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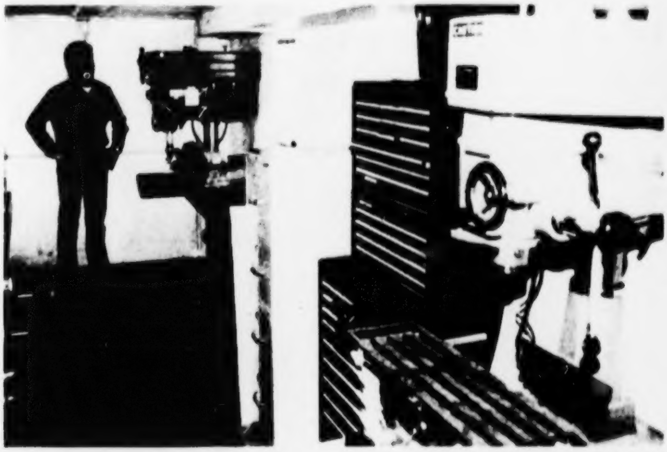

Figure 4
Interior View - Left Side

25.1

The Development of a Software Architecture for Communication Systems

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Abstract – This paper describes the philosophy, goals and current results of the *Software Architecture* project. Its objectives are to develop a specification for the design of software-based communication devices and to implement this design in a module library and application program. The design will facilitate the sharing of results between researchers and the module library will accelerate the development of marketable products.

Introduction

As computer hardware used for augmentative communication systems becomes more powerful, there is a natural tendency to create more sophisticated applications. As in all applications software, it is generally perceived that increased functionality results in greater benefits for the end user. We as developers of these systems are faced with two major challenges. First, when compared to many other application areas there are very limited resources for systems development. For example, commercial software companies producing PC-based applications can recoup large development costs by selling a large number of units at a low price (e.g., word processor) or by selling a small number of units to a market that can afford to pay high prices (e.g., CAD/CAM). Augmentative communication systems have a relatively small user base with limited resources. The second challenge is meeting the needs of an extremely diverse user population. For example, a keyboard and mouse provide a suitable interface for most able bodied people. The input interface for AAC users must by necessity be tailored to each individual.

The major goal of this project is to provide mechanisms that will facilitate the sharing of ideas and implementation efforts among augmentative communication system researchers, and to provide tools that will allow the development of a greater number of systems.

Background

The discipline of software engineering has developed conceptual tools for organizing complex software systems. Among the most useful ideas are the concepts of a system *architecture* and of software *modules*. An architecture is described as a hierarchical structure of procedural components and data. It is "derived through a partitioning process that relates elements of a software solution to parts of a real-world problem" [Pressman, 1987]. Modules are conceptually independent components of a software system, and serve to provide boundaries that isolate the entire program from local changes.

Most modern languages support modules as separately compilable units (e.g., C, Modula-2). In this way, a developer or group of developers can work on a module independently and link it to the rest of the system when necessary. Separate modules also allow testing to be performed at the component level. The relationships between modules must be well defined for this process to work.

To develop a software architecture, it is necessary to examine the functional requirements of a real world system (or family of systems) and to partition the software design into a set of modules. To allow the architecture to be general, we must design interfaces between modules such that new modules can be developed and *plugged in* to an existing system. This is best illustrated with some scenarios.

Input – A system consists of a number of input modes including scanning and directed scanning, that use the standard PC game adapter interface. A developer wishes to develop a new input mode that uses six switches. Four switches would be used for cursor movement, the fifth switch would be used for select, and the sixth switch would be used to cancel the last selection. These switches would be interfaced to a bi-directional parallel printer port. Adding these capabilities would require two steps. First, the developer would develop a hardware driver to read the port. Second, the developer would create a module that implemented the 6 switch input mode. These two modules could then be added to the system.

Rate Enhancement – A system provides abbreviation expansion, and a developer wishes to make abbreviations sensitive to previous punctuation. For example, if the user typed ' t ' the system would substitute ' the '. If the user typed '.t ' the system would respond with '. The '. In this case the developer would either modify the existing abbreviation expansion module, or create a new one.

Previous work has been aimed at similar goals. Demasco et. al. [1987] developed a C function library for MS-DOS based communication systems. McDougal et. al. [1988] developed a model for alternative access devices to computers. Finally, Minneman and Pham [1986] developed a control language for rehabilitation robotics. Although the latter two papers are directed towards different rehabilitation technologies, there is a great degree of common ground between all of the work (e.g., input strategies).

Methods

We expect to produce within this project three major products. These are: 1) an architectural specification; 2) a module/class library for other developers; 3) an application(s) that uses the library. These objectives will be fulfilled in five major project phases:

Needs Analysis – An analysis of current and future clinical needs as well as a survey of current communication systems. We ask the question: what should AAC systems of the future be able to do?

Architecture Requirements – This phase focuses on the goals of the software architecture, and how to achieve them. What must the architecture define in order to encourage effective sharing of ideas and implementation effort among AAC researchers?

Architecture Design – Next, a general architectural framework for AAC systems will be designed. This architecture will define the major components of a communication system and how they fit together. It will specify the interfaces and capabilities that must be adhered to in order to produce software *interchangeable parts.*

Communications System Design – The design of a specific augmentative communication system which fits the architectural specification will be the fourth major phase. This design will provide a concrete example of how the architecture can be used.

Development – Finally, the class/module library and an AAC application will be developed, including auxiliary programs such as vocabulary configuration tools for clinical use. This phase will include the development of documentation and examples to help developers who wish to modify or extend our system to fit their needs.

Results

Although the project is still in a relatively early stage, a number of results merit reporting.

Object-oriented Programming
One of the foundations of the current work is the selection of appropriate tools for the design and the implementation of the architecture. A powerful method of software engineering has recently emerged called *object-oriented programming*. One of the principal aims of object-oriented programming is to facilitate the development of software modules which can be reused in a variety of settings [Meyer, 1988]. As this is consistent with the goals of this project, we rely heavily on principles of object-oriented design in our work.

Although object-oriented programming can be viewed purely as a design philosophy, it is generally tied in with the programming language that is used for development. There are an increasing number of object-oriented languages becoming available to developers. We have chosen C++ as our development language for a number of reasons including efficiency, support (i.e., popularity), and compatibility with C (which at this point is one of the most popular applications development languages).

Needs Analysis
At the 1988 ISAAC conference in Anaheim, a meeting was held with a number of augmentative communication clinicians to describe the project's goals and to receive initial input on user's needs. Among many issues discussed, several dominant ones emerged.

Flexibility – The diversity in the user population can only be addressed by a greater degree of flexibility in system configuration. important areas of device operation that must allow for flexible configuration include input devices, input modes, and vocabulary structure.

Clinician/User Programming – System flexibility can only be properly harnessed through an effective programming interface. The device user and clinician should have full control over system configuration. This control must be balanced with quality documentation, and a variety of example configurations.

Graphics – To reach users who need to use symbol systems or need large character displays, it is an absolute necessity that graphic displays be fully supported.

Conclusion

An essential ingredient to the success of this project is collaboration. A secondary purpose of this paper is to invite anyone who is interested in the goals and outcomes of this project to offer input. The project staff is in the process of developing a mailing list that will receive updates on the project's progress and an opportunity for feedback.

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25.3

RECIPE PREPARATION BY A SEVERELY IMPAIRED APHASIC USING THE C-VIC 2.0 INTERFACE

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ABSTRACT

At the VA Rehabilitation R&D Center in Palo Alto, CA, work is underway to develop and evaluate a microcomputer implementation of a visual communication system for severely impaired aphasics. The system incorporates a vocabulary of representational and ideographic icons, a language-like syntax, and a specially designed interface which uses a "mouse" computer pointing device to control events on a high-quality graphics display. This paper reports on new features recently added to the system to provide greater power and flexibility, describes the system's use to support one type of complex task performance — namely, recipe preparation — by a severely impaired aphasic person, and offers some observations on strengths and weaknesses noted in the subject's performance.

THE C-VIC INTERFACE

We have been working to develop the "Computer-aided Visual Communication" (C-VIC) system for rehabilitation of severely impaired individuals.[1] As described in a previous report[2], the C-VIC system runs on an Apple Macintosh computer, features a complex, window-based, hierarchically organized interface, utilizes pictographic or iconic vocabulary elements, employs a formal syntax, and is operated solely by use of the "mouse" cursor controller. Recently we have incorporated several new features into the interface which make it significantly more flexible and powerful, including the following:

Animation: icons in Version 2.0 are animatable. While these animations are brief, comprising twenty frames altogether and lasting between 2-3 seconds, they provide a powerful way of depicting the actions of verbs, as well as the sense of certain nouns, adjectives and prepositions.

Scene-like presentations: in the new version, icons may be of any size or shape whatever, and they may be placed against a background scene. This shows them in context, indicating where an object is found, its relative size, and its expected location vis-a-vis other objects in the scene.

Programmability: Version 2.0 allows researchers to construct and store up sequences of communications beforehand, both in the access area and in the communication spaces. With this capability, investigators can prepare recipes or other sequences of instructions to assist aphasic trainees in the execution of complex tasks.

THE TARGETED APPLICATION

We previously reported various targeted applications to be supported by the C-VIC interface[3]. Here we describe in greater detail how the system is configured to serve in one such capacity — as an *aid for complex task execution*, supporting recipe preparation. The metaphor which is used in this application is that of a "notepad": the various steps of the recipe are listed in sequence on the individual pages of this notepad, and the user can leaf backward and forwards through the notepad to interpret the meaning of individual instructions, gain perspective on the overall task, and build up strategies for proceeding.

Fig. 1: SAMPLE C-VIC 2.0 SCREEN

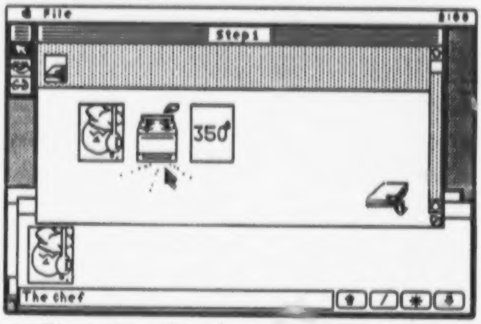

Fig. 1 above shows how one such cooking instruction appears on the screen of the computer. Its meaning is "The chef turns on the oven to 350 degrees". The small icon of the chef and of "350 degrees" are static, but the grey arrow beneath the stove indicates the icon above it is animatable. If the user "clicks" the mouse on it, the small hand descends and turns one of the knobs on the stove, and then the door to the oven flashes twice to indicate which element (burner or oven) is to be turned on. When the user has completed this step, he clicks on the small notepad to the lower right, which reveals the instruction of "Step 2", on the next page. If the user wants the English translation of the communication, he drags it down into a communication space at the bottom of the screen, where both the icons and English translation are displayed. For illustration purposes, we have shown a single icon, of "The chef", moved into this space.

SUBJECT DESCRIPTION

The work reported below involved a single subject, JN. He is a 48 year old, right-handed man, who was in good health until 1974, when he suffered a head injury in a motorcycle accident and subsequently underwent a partial frontal lobectomy. Since that time, JN has suffered from a severe expressive and receptive aphasia. On the Boston Diagnostic Aphasia Examination (BDAE), JN shows subscores near or at the zero level for naming, reading and repetition. A Profile of Speech Characteristics reveals profound impairment in fluency of free speech and absence of melodic line. The assessment tools place him in approximately the 7th percentile in overall verbal ability, with oral expression limited to a very few stereotypies. Spontaneous written expression is confined to highly routinized sequences, such as the patient's name and address, while the patient exhibits moderate ability to copy, occasionally replacing printed forms with cursive script forms. There is no comprehension of written material.

PERFORMANCE OBSERVATIONS

Between November 1988 and February 1989, we worked with JN in fourteen sessions, presenting six different recipes using the C-VIC 2.0 system. The recipes used are all for commercial box mixes, in which many ingredients have been pre-processed and mixed. The dishes prepared span a spectrum of difficulty: the simplest ones required only that all ingredients be mixed together and then cooked; more difficult recipes have involved two or more "tracks", e.g., preparing a frosting for gingerbread while the latter is cooking. We take a functional approach towards judging success: a dish must be prepared essentially as was intended, resulting in an edible and tasty product. In this context, our subject has performed successfully in 11 out of 14 trials (78.5%). In his performance, JN reveals the following pattern of successes, failures, and uncertainties:

Strengths of JN's system-based peformance: Using C-VIC, JN can prepare recipes independently, setting his own pace, reviewing and previewing individual steps at his discretion, and using the software to support performance in the ways that he chooses. In preparing recipes using the C-VIC system, he does not omit ingredients, nor does he add them in significantly wrong amounts. When items are cooked, they are either cooked at the specified temperature for the specified time, or else JN deliberately deviates from the recipe on the basis of constant monitoring and considered judgement (which is frequently adequate in this regard). Depending on the recipe, these latter factors alone may be adequate to ensure that a recipe is adjudged successful upon completion, regardless of what else happens.

Weaknesses of JN's system-based performance: If deviations from JN's expectations occur in a recipe instruction, JN may ignore part or all of the instruction and proceed according to his expectations. If the sense of the instruction is incomprehensible to him, he again may ignore the instruction or improvise. In this regard, instructions in C-VIC format appear more to *suggest* than to *command*. When JN loses confidence in his interpretation of the C-VIC instructions, he often finds inadequate corroboration in the single recourse now provided by the system — instruction review and preview capabilities. JN demonstrates that he sometimes needs more of a global overview of the recipe than is presently provided; merely walking him through all the individual steps appears too complicated to provide him the "chunked" overview from which he might benefit. JN also is given to a fair amount of random activity, such as adjusting the flame on burners when not instructed, stirring ingredients without instruction, or turning burners on or off when new instructions are encountered.

CONCLUSIONS

C-VIC Version 2.0 is a versatile and powerful interface which can be configured to support, among other things, recipe preparation. In cooking trials with a single severely aphasic subject, we have demonstrated that the system is capable of supporting successful independent recipe preparation much of the time, though not all of the time. In these studies, the areas of both strength and weakness in recipe preparation have been identified, and work is underway to learn how to build further on the strength and avoid the weaknesses. It appears that a successful strategy may involve at least the three following elements: a) selectivity in choosing types of recipe; b) refinements in the way in which the system presents recipes to users; and c) new training protocols to help prepare users for successful independent performance.

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25.4

New Methods for Pitch Change During Time-Domain Waveform Coded Diphone Speech Synthesis

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Introduction

At the Applied Science and Engineering Laboratories (A.S.&E.), a library of diphones stored as time-domain waveforms is being completed. Speech synthesis using diphone concatenation allows for unlimited vocabulary and provides a convenient way to handle the complicated acoustic transitions from one phoneme to another (Boubekker,1985). Diphones stored as time-domain waveforms allows precise cutting and marking of the diphones. However, it is very difficult to alter intonation of utterances stored as waveforms (O'Shaughnessy, 1988). Yet without pitch contours, it has been found that listeners have difficulty comprehending speech. Listeners have trouble focusing on monotonic speech and often miss key syllables. When pitch contours are imposed upon an utterance, the intelligibility of the synthesized speech improves dramatically (Willems, 1982). Such contours give tremendous cues on the meaning of the utterance. They allow utterances to be linked coherently, indicate endings and pauses in utterances, indicate the nature of the utterance (declarative, etc.), and indicate stress on a word or syllable (Willems, 1982). For most utterances, it appears that pitch contours can be limited to five rises and five falls. Dutch researchers have found that there are a limited number of recurrent pitch patterns in utterances (Willems, 1982). Presently, the A.S.&E. is developing a method of overlaying pitch contours onto waveform-coded diphone concatenated utterances.

Methods

The method developed for overlaying pitch contours involves varying the sampling rate of playback of the message while compensating for the changes in duration of the speech segments. The method consists of three steps.

The first step consists of developing a library of time-domain waveform coded diphones. The library is being extracted from natural utterances using the Interactive Laboratory Systems speech package by Signal Technology, Inc. Diphone locations and information is stored in an inventory table. The inventory table also holds values that mark the location of the beginning and ending pitch periods of each diphone. By the nature of diphones, these pitch periods are located at the steady states of the respective phonemes. Therefore, these pitch periods can be repeatedly inserted into an utterance in order to increase the time duration of an utterance.

The next step is concatenation of the diphones while inserting pitch periods at locations associated with increased pitch. This step involves a program that concatenates the diphones and varies their length (or time duration) in accordance with the specified pitch contour. The resulting data is then used by the playback module.

The final step is to play back the diphone data file at varying frequencies, depending on the pitch contour. This is accomplished through a playback module that can dynamically alter the sampling frequency at which data is played back. The playback module is designed to work with the Data Translation 2821 analog and digital I/O board and real-time clock. The perceived pitch varies inversely with the sampling rate. The base rate is around 10,000 samples/sec.

Results

Preliminary results indicate that such a method will provide quality speech with natural sounding contours. When this method is used with simple ramping (a gradual but steady increase in the rate at which data is played back) and one contour change, pitch varies noticeably and sounds natural. The time duration of the utterance is also acceptable. Changing the duration of the utterance by splicing on pitch periods from both ends of each diphone lead to smooth and natural sounding utterances.

Discussion

Changing pitch by changing the frequency at which data is played back is very acceptable to the human ear. Both ramping and abrupt but not drastic changes in frequency sound natural. The results of repeatedly adding pitch periods to the diphones also results in natural sounding speech of longer duration. However, certain limitations exist in increasing the duration of a concatenated utterance. Since pitch periods are of a specific duration, there is no way to lengthen an utterance to an exact length for each specific pitch. Instead, each additional pitch period makes the duration of an utterance acceptible for a certain range of pitches. In other words, for the pitch of an utterance to vary from 230Hz to 353 Hz, its duration would be increased by 8 quantum. The relationship between increased pitch and increased duration is linear.

Another limitation in increasing duration is that certain phonemes have no steady states. For example, plosives have no pitch periods. Plosives were cut so that the end of one diphone was the silence before the burst, and the start of the following diphone was the burst. Any attempt to increase their duration sounds awkward and disjointed. Fricatives have no pitch periods either. It is possible to mark a certain length of noise during the fricative which can be repeated to lengthen the diphone. Results are more natural sounding, however, when fricatives are concatenated with no increase in duration. It was also found to be necessary to include glides completely within a diphone. When attempting to cut and splice glides like other sonorant phonemes, the resulting utterance is not smooth and continuous. However, the actual duration of plosives, fricatives, and glides compared to other sonorants in most utterances is relatively small. Therefore increasing the duration only of those phonemes with consistent pitch periods produces utterances of sufficient duration for most increased frequencies.

Limitations also exists concerning the decrease in duration of an utterance when decreasing the pitch of an utterance. When recording the diphones, a base pitch is established. In order to lower the pitch below the base pitch, the length of the utterance would have to be decreased rather than increased. To do this, more pitch periods would have to be marked in order to eliminate pitch periods rather than repeat them. This would result in increased storage required, but is not necessarily a problem. However, eliminating pitch periods makes the transition from one diphone to another less smooth. Each eliminated pitch period makes the end pitch periods more likely to be affected by previous or following phonemes. The transition from one diphone to the next is therefore more likely to be disjointed. Another method must be found for decreasing pitch.

The next step will be to develop pitch contour models that sound natural and aid in the intelligibility of an utterance. Both Mattingly and Witten have developed a set of explicit rules for generating pitch contours (Pijper,1983). However, multisyllabic words are frequently misunderstood when uttered monotonically. In order to increase their intelligibility, stressing certain syllables is useful. Since the most salient feature for indicating stress is pitch change (Holmes, 1988), it may be beneficial to develop a dictionary of pitch contours for individual words. Such a dictionary would increase the intelligibility of individual synthesized words both when uttered alone and within a stream of utterances.

Acknowledgements

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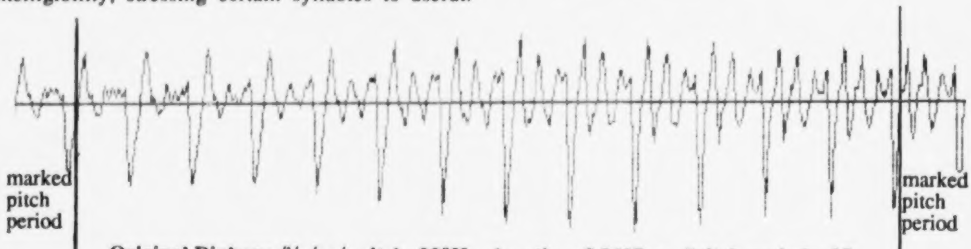
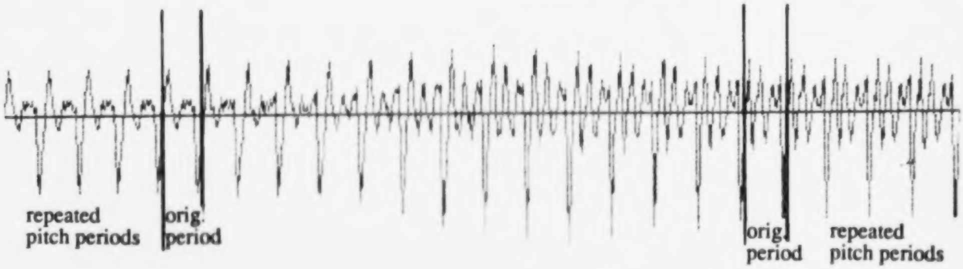


Original Diphone /i/+/aa/: pitch=230Hz, duration=0.0627sec, #pitch periods=15



Lengthened Diphone /i/+/aa/: pitch=353Hz, duration=0.627sec, #pitch periods=23

25.5

A FIRMWARE BASED BATTERY MONITORING SYSTEM FOR A VOICE OUTPUT COMMUNICATION AID

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ABSTRACT

A low-cost firmware-based battery charge state monitoring system is developed for a voice-output communication aid utilizing dynamic ram. The system greatly reduces the risk of inadvertent loss of memory by providing adequate warning to the user of a low-battery condition.

INTRODUCTION

Considerations of portability, economy, and convenience demand that most electronic communication aids utilize re-chargable batteries for a power supply. In the case of a voice output aid utilizing digitized rather than synthesized speech, the large amounts of memory required dictate that dynamic RAM be used in order to keep costs down. Programming a device with a user's vocabulary represents a significant investment of time and effort that must be protected from loss. Requiring the user to charge the batteries on a daily basis would be inconvenient and time-consuming, as well as resulting in memory effects which would tend to degrade battery performance. Furthermore, under conditions of extremely intensive use, it might still be possible to discharge the batteries at a high enough rate to cause loss of memory in a single day.

Thus there is a need for some mechanism to provide feedback to the user regarding the charge state of the device to indicate when and how long the device needs to be charged. In order to prevent inadvertent memory loss, further use of the device should be restricted once the charge on the batteries drops below a critical threshold. However, this mechanism needs to be under user control so that critical communication needs can be met even when the batteries are below this threshold. Due to the difficulties in designing an effective hardware-based charge monitor and the complexity of the required interaction between user and device, a firmware-based battery monitoring system was developed.

BACKGROUND

The use of dynamic RAM results in a significant current drain just to maintain memory contents. In the device for which the battery monitoring system was developed (the IntroTalker from Prentke Romich Co.), the average measured standby current when refreshing 256 Kbytes of DRAM was just under 5mA. This value reflects the total current drain on the system when the only activity that occurs is due to the need to refresh memory. Memory refresh was performed by waking up the main processor every 4 ms and executing 256 bytes of sequential code while gating the lower 8 bits of the address bus (plus a ninth bit toggled at each refresh cycle) to the DRAM row address and pulsing the Row Address Strobe line.

A hardware battery charge monitor was designed by feeding the output from a voltage divider into a transistor (monitored by the main processor) which changed state when the voltage dropped below a critical threshold. However, the voltage output of the NiCad batteries decreases slowly with only slight variation up until it starts to drop severely. Since it was necessary to allow for variation in battery performance, it was not possible to set a threshold that would reliably detect significant change more than 4-5 hours before the end of useful battery life. However, this circuit was retained in the final product as a check against the calculated battery state in the firmware monitor.

The development of a hardware current monitor was also considered, since it would be possible to periodically measure the voltage drop over a resistor to estimate the current drain. However, this approach was rejected because it would entail significant additional hardware costs, and the sampling points might not reflect the real state of the device over time.

METHODS

The battery monitor is based on the fact that there are only a limited number of possible states of the device, and that the actual average current drain associated with each of these states can be measured. Since changes in the state of the device occur at a relatively low frequency, a value representing the charge state of the batteries can be maintained by adjusting it at fixed intervals according to the current drain associated with the state of the device. Each time the state of the device changes, the value of the current drain can be adjusted to reflect the new state. When the device is being charged, the charge state variable can be adjusted by a value reflecting the average charge rate. By deliberately choosing conservative values for the various current drains and the average charging rate, it is possible to avoid a situation where underestimation of the current drain values would cause the charge state variable to get "out of phase" with the actual state of the batteries.

The charge state variable is a four-byte integer representing the amount of charge drained from the fully-charged state (represented by a value of 0). The lowest order byte represents mA-sec/256, so the highest order byte represents units of 18.2

ma-hrs, and counts up to a limit of 110 (2000 mA-hrs, the total capacity of the batteries). The device was placed into the various possible states so that the current drain associated with each could be measured. An analysis of the system's operation determined the possible combinations in which these states could occur. Measurements were performed to verify whether certain combinations might need to be defined as special states because of non-linearity due to interactions between the component factors contributing to the total system current drain. Conservative estimates of the current drain associated with each of the linear component factors identified were then expressed in units of mA. The one state for which it is not possible to identify a truly reliable estimate of current drain is when the device is speaking, due to the relatively high current usage and the wide variation due to output volume setting and original source level. However, here again a conservative estimate was used, and in actual use of the device the amount of time spent in the speaking state would be generally quite limited compared to other states.

The 256 byte memory refresh code segment is executed every 4 ms when the system is inactive (low-power mode) and every 3.6 ms when the system is active. The current drain is re-calculated at each change of state, and this value is added to the charge state variable at each refresh interrupt. If the batteries are being charged, the average charge rate (in mA) is added to this variable. When the device is first powered-up, it is not possible for the system to know the state of the batteries. A fully discharged state is assumed, and the battery monitor's warning system is disabled until the device has been on the charger long enough to reach a fully charged state. Three thresholds are defined at 1/3 and 2/3 discharged (as estimated by the monitoring system), and fully discharged (either estimated or when detected by the hardware voltage monitor). Different actions are taken depending on the threshold passed and control input from the user.

After the first threshold is passed, the device will begin to speak the message "Battery is low" every 1/2 hour on the assumption that the device may be sitting unused somewhere, and that there is a need to get someone's attention to inform them that the device needs to be charged. In addition, an LED located next to the charger input jack flashes once every 8 seconds, in case the volume is turned all the way down. The message is not spoken more often in order to avoid adding too much demand on the batteries by speaking frequently. When any key is depressed in this state, the message is spoken immediately (since a listener is known to be present), and this message output is then disabled for one hour, since the user has been informed and the batteries are not yet in a critically low state.

After the second threshold is passed, the output message changes to "Battery is too low", and the same behavior continues (the charger LED now flashes twice every 8 seconds). However, when a key press is detected at this point, the message is output and the device shuts down and does not respond to any further key presses until the system is placed on the charger. However, by pressing one of the control keys and holding it for 5 seconds, various control parameters can be set, one of which disables the battery monitor warning system and again allows the device to be used normally. After this, it would be possible to use the system to the point where loss of memory would occur, but this is clearly the user's choice and prerogative. The output from the voltage sensor also forces the charge state counter into the fully discharged state in order to ensure that the counter stays synchronized with the true state of the batteries.

Once the counter reaches the final threshold (fully discharged), it is held at that level so that it will count back down to 0 (fully charged) when placed on the charger for the required time interval. Placing the unit on the charger immediately disables the battery monitor warning system and allows the device to be used. When the counter reaches 0, the message "Battery is full" is spoken once, and is repeated when the charger is removed. If the charger is removed while the counter is still below the first or second threshold, the warning system is re-enabled and the appropriate message ("... low" or "...too low") is immediately spoken.

RESULTS AND DISCUSSION

The device has been tested internally for about 6 months, and the battery monitoring system has performed as expected. Units were being shipped out into the field 3 months prior to the time of writing, and about 600 units have been shipped. The absence of any complaints regarding the loss of memory or other difficulties with maintaining an adequate charge seems to indicate that the battery monitoring system is functioning as intended in actual application. It is easy to imagine other applications in the rehabilitation engineering field which might benefit from a similar approach. Any microprocessor-based battery-powered device could use a similar monitoring system even if speech output were unavailable, since the warning could be communicated to the user in a variety of ways. The system adds only a negligible cost to the system, and carries considerable potential benefits in terms of device convenience and reliability.

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26.1

CHARACTERIZATION OF A FORCE-SENSITIVE RESISTIVE TRANSDUCER FOR APPLICATION TO PROSTHESIS CONTROL

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ABSTRACT

A force-sensitive resistive material has been incorporated into a force-actuated position-servo controller applicable to multi-joint electric-powered upper-extremity prostheses. The material has many desirable features: minimal displacement, low fabrication cost, low power consumption, easily varied geometry, and small size. Experiments conducted to identify sources of variance in the resistance vs. force relationship are described.

INTRODUCTION

Prior research and clinical experience indicates that users of powered multi-joint upper-extremity prostheses give considerable attention to the control of their prostheses. The effective use, i.e. with low mental loading, of more than two powered joints in *coordinated* movements does not appear possible using "velocity-control" approaches, such as switch and myoelectric controllers.

To achieve improved control of a multi-joint prosthesis, a force-actuated position-servo controller has been proposed to couple one or more anatomic joints to one or more prosthetic joints. This type of controller is based on Simpson's concept of extended physiological proprioception (EPP) (1). Effectiveness of the control had been demonstrated empirically in Simpson's applications to gas-powered prostheses (2) and experimentally in comparisons with velocity control of electric-powered prostheses (3).

BACKGROUND

Crucial to a clinical evaluation of an EPP-controlled prosthesis is the force transducer, which provides the control signal. A load cell had been used in an experimental prototype, but the power requirements and size of this transducer did not suit it well for clinical use. Additionally, the high accuracy of instrument-grade commercial load cells, which increases their cost, was not deemed necessary in a prosthesis controller limited by the force and positioning accuracy of an anatomic joint. A force transducer was required which combined minimal displacement, low power consumption, small size, ruggedness, low cost, and useable (but not high) accuracy.

After investigating several alternative force transduction techniques, a commercial force-sensitive resistive (FSR) material[1] was selected as the most promising. The material is a thick film sandwich of electrically conductive and resistive polymer layers silk-screened onto a Mylar™ backing in user-specified patterns. Unloaded, the material has a resistance on the order of 10 to 100 Megohms.

A series of experiments were conducted to characterize the FSR resistance vs. force relationship and to identify sources of variance in the relationship relevant to the construction of an FSR-based force transducer.

METHODS

All experiments were performed using three 1/2 in. (12 mm) diameter disks of FSR material, from the same processing batch, silk-screened onto 3-mil Mylar. The FSR disk was placed in opposition to parallel gold-flashed contacts etched from a circuit board. The contacts covered the entire surface of the FSR disk, extending beyond the perimeter of the disk, except for the gap between the contacts. Four sets of contacts were evaluated: two were made with gaps of 0.016 in. and 0.069 in. widths and with no filler material within the gap, i.e. the "floor" of the gap was 0.001 in. below the surface of the contacts; two were made with gaps of 0.016 in. and 0.087 in. but with the gap filled in with a non-conductive epoxy flush with the surface of the contacts.

The FSR and contact set were placed in a self-leveling loading fixture with a thin sheet of cardboard between the Mylar backing of the FSR and the face of the loading plug. A 22 Kohm resistor was placed in series with the FSR with 4.0 v across the voltage divider network. A set of discrete loads were applied to the FSR/contact assembly. The loads were sequentially increased from 1.08 lb_f (4.80 N) to 21.84 lb_f (97.14 N), then decreased in reverse order. At each change in load, approximately ten seconds were allowed before taking readings. The voltage across and current through the FSR were measured and the resistance calculated.

RESULTS

Resistance vs. force relationship

Figure 1 is a plot of the average FSR resistance vs. force for one FSR disk. The average is of three trials in which the loads were sequentially increased, then decreased. The gap between the conductive contacts was 0.069 in. and was unfilled.

Inter-contact gap width

Figure 2 shows the averaged resistance vs. force data for the same FSR disk in opposition to contacts separated by 0.069 in. (1.75 mm) and 0.016 in. (0.41 mm) for increasing and decreasing loads. Standard deviation indicators have been omitted for clarity.

Inter-sample variation

Figure 3 shows the averaged FSR resistance vs. force

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[1] Interlink Electronics, Santa Barbara, CA

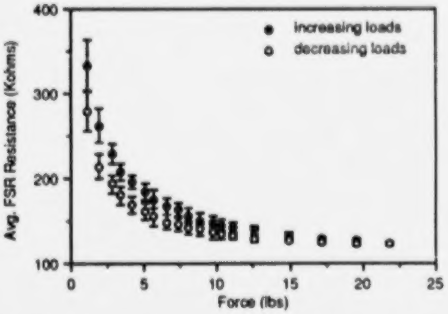

Figure 1. Average FSR resistance (± one standard deviation) vs. force for three trials with sample #32.

data for three FSR disks (all from the same processing batch). Only the averaged data points for the increasing load sequences are shown for clarity; however, hysteresis, as a function of the direction in which the loading changed, was evident for all three FSR disks.

DISCUSSION

The FSR material clearly does not qualify for a force transducer requiring high accuracy. It exhibits a significant degree of inter-trial variation in resistance for a given load and sample (Figure 1) and may show considerable variation between samples (Figure 3). It also exhibits a significant degree of hysteresis (Figures 1 and 2).

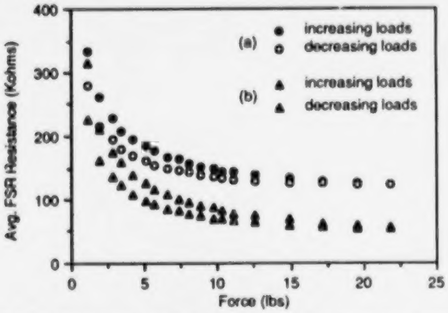

Figure 2. Average FSR resistance vs. force for three trials with each of two contact separations: (a) 0.069 in. and (b) 0.016 in.

Narrowing the inter-contact spacing (Figure 2) lowers the average resistance at a given load. The narrower spacing also increases the negative slope of a regression line fit to the data between 2.5 and 15.0 lb_f when plotted on log/log scales. Though the data is not presented here, having the inter-contact space filled or not made relatively little difference in the shape or position of the resistance vs. force relationship.

CONCLUSIONS

The FSR material tested shows significant inter-trial and inter-sample variation. However, the

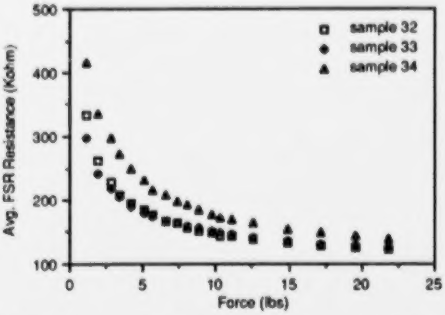

Figure 3. Averaged resistance vs. force data for three FSR disks for sequentially increased loads. Conductive contacts separated by 0.069 in.

inter-trial variation in the log/log region, between 2.5 and 15.0 lb_f, for a given sample is within acceptable limits for evaluation as a force transducer in a clinical EPP-controlled prosthesis. It is believed that the degree of variation in resistance expected in this region (Figure 1), as well as the nonlinearity and hysteresis of the relationship to force, can be accommodated by the user because of the close control/feedback coupling of the user and prosthesis.

A prototype transducer and EPP-controller (calibrated for the particular FSR sample used) has been constructed and is being tested.

ACKNOWLEDGEMENTS

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26.2 DESIGN OF A MODULAR EXTENDED PHYSIOLOGICAL PROPRIOCEPTION CONTROLLER FOR CLINICAL APPLICATIONS IN PROSTHESIS CONTROL

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ABSTRACT

A prosthesis controller based on the concept of extended physiological proprioception (EPP) has been developed for clinical application. The controller's force transducer and electronic conditioner/driver are described.

INTRODUCTION

The efficacy of prosthesis control by extended physiological proprioception (EPP) has been demonstrated empirically by Simpson and his co-workers (1). They developed and applied the concept to children born without limbs who were able to operate pneumatically-actuated total arm prostheses by shoulder movements. EPP control has subsequently been shown experimentally, by Carlson (2) and by Doubler and Childress (3), to be superior to velocity control—the type of control achieved with switches and myoelectric controllers—of electric-powered prosthetic joints.

The objective of the work described was to develop a generalized EPP controller that can be applied to electric-powered positioning joints and to refine the design for clinical application.

BACKGROUND

The essence of EPP control is to utilize the movement on an intact physiological joint to control one or more prosthetic joints and to link the joints mechanically so that the proprioceptive senses of the intact joint can be used to determine the position and movement characteristics of the prosthetic joint. Simpson's EPP controller used a position-servo system to couple the joints together. However, the relative error in positions needed to derive the control signal weakened the coupling between the two joints.

To minimize the positioning error, Doubler and Childress (3) implemented a force-actuated position-servo in which the position of the physiological joint determined the position of the prosthetic joint, but the force in a rigid mechanical link between the two joints provided the control signal. A custom load cell measured the force in the linkage.

The power requirements and size of the load cell did not suit it well for clinical applications. It's high accuracy (and cost to achieve) was also felt to be unnecessary in a prosthesis controller limited by the accuracy with which forces can be produced by muscles crossing an anatomic joint.

As a step toward clinical implementation of an EPP controller for electric prostheses, a force transducer based on a commercial force-sensitive resistive material (4) and its associated electronic signal conditioner and driver have been developed.

DESIGN

Force transducer

The transducer is shown in Figure 1.

In use, the transducer is mounted to the moving segment of the prosthesis distal to the prosthetic joint. The dacron cord is the mechanical link between the physiological joint and the prosthetic joint. The cable housing guides the cord, as it does for standard steel cable in a cable-operated prosthesis, and provides a reaction force against the force pulling on the cord. Within the plastic housing of the transducer, the cord passes through the center of an FSR disk in opposition to a set of electrical contacts and is tied off distally. Tension on the dacron cord compresses the electrical contacts against the FSR disk producing a change in resistance of the FSR material, which is converted to an electrical signal to drive the prosthetic joint.

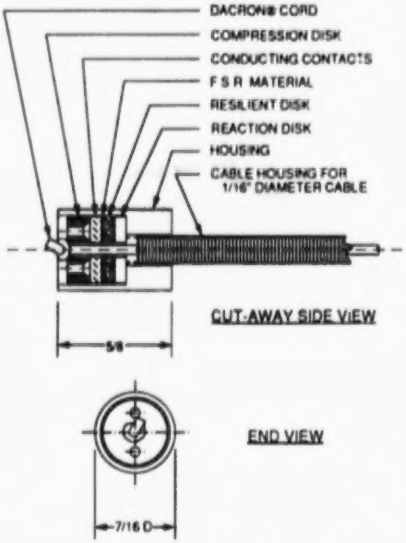

Figure 1. Side and end views of the force transducer.

The transducer is packaged in a volume smaller than 1.0 in^3 (16.4 cm^3) and is very low in weight. It is also somewhat rugged because of its enclosure and because it can be mounted within the distal segment of the prosthesis.

Electronic conditioner/driver

The conditioner/driver converts the change in resistance of the FSR material into a proportional signal to drive the motor of the prosthetic joint. Figure 2 shows an idealized relationship between the force applied to the FSR transducer and the resultant control signal.

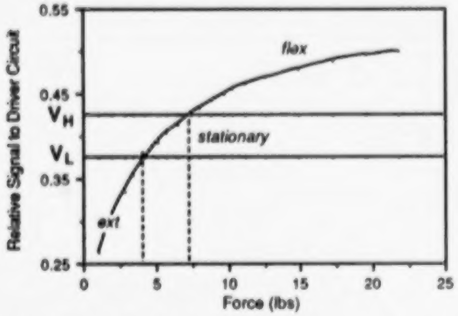

Figure 2. Idealized relationship between the force exerted by the anatomic joint and the resultant control signal for an FSR-based force transducer.

Two thresholds (V_L and V_H) are shown on the graph. If the signal derived from the force transducer is below the lower threshold (V_L), the prosthetic joint is driven in one direction. If the signal is above the higher threshold (V_H), the joint is driven in the other direction. The magnitude of the difference between the transducer signal and a threshold, i.e. above V_H or below V_L, is proportionally related to the power applied to the motor. By directing the physiological joint to a particular position, thus increasing or decreasing the tension in the linking cable above or below the corresponding threshold, the user directs the prosthetic joint to move in concert to a corresponding position. By holding the physiological joint in place and maintaining the control signal (by maintaining the tension in the cable) between V_L and V_H, the user holds the prosthetic joint in place.

The electronic package includes surface mount components and is configured on a circuit board approximately 1.25 x 2 in. (3.2 x 5.1 cm). In operation, the controller draws less than 700 μa.

Clinical implementation

In preparation for field evaluation, a person with a unilateral shoulder disarticulation has been provided with a Hosmer electric elbow operated by the EPP controller. Two harnessing arrangements are under investigation. One is, in outward appearances, essentially identical to the arrangement for cable-operation of a mechanical elbow using biscapular abduction, except that the control cable is linked to the force transducer and biscapular forces and movements control the movements of the electric elbow through the EPP controller. The second is a torso frame and shoulder cap arrangement in which the shoulder controls flexion and extension of the elbow by elevation and depression.

DISCUSSION

Several specific factors related to the implementation of the described EPP controller are under investigation in the clinical fitting. First, the FSR material in the force transducer produces a nonlinear relationship between resistance and force which also exhibits hysteresis with respect to the direction of change in force (4). Second, for simplicity in control harnessing, the anatomic joint and prosthetic joint are rigidly coupled only for flexion of the elbow. Maintenance of the coupling during extension is dependent on the dynamic response of the elbow and the rate at which the user reduces the force below the controller's lower threshold. Third, to preserve the coupling and sense of the prosthetic elbow's position when the elbow is held flexed, the user must maintain the position of the anatomic joint to hold the prosthetic joint in the corresponding position and, therefore, hold the tension in the linking cable between the two thresholds.

It is felt at this time that the relative importance of these factors can best be discerned through the direct experience of a trial user.

ACKNOWLEDGEMENTS

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GRADUAL SCREW REMOVAL IN BONE PLATING

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ABSTRACT

This study explored the biomechanical feasibility of gradual screw removal for the reduction of stress shielding in plated bone. Preliminary results from a 2D finite element (FE) Model describe a pattern of changes in the stress distribution due to sequential screw removal. These results suggested that removal of one or even two pairs of screws did not seem to subject the remaining screws to significantly higher stresses, so long as the fracture site had closed and attained a stiffness at least 1/10 of that of the normal bone tissue. Removal of outer screws allow a larger bone portion to experience a more normal stress distribution.

INTRODUCTION

Stress shielding associated with rigid plating in bone fracture rehabilitation has long been regarded as a reason for refracture after the fixation system is removed[1]. Such problems could only be worsened by the presence of screw holes after the screws are retrieved. The optimal rigidity for fracture healing is likely to vary during the healing process. As the bone heals, it is desirable to allow the bone to bear an increasing proportion of the load. Such effect can be facilitated if the rigidity of the fixation system can be gradually reduced as the healing progresses. The present research explores the idea of gradual screw retrieval (GSR) as a clinical procedure to reduce the rigidity of a plate-screw fixation system. To implement this procedure with minimal surgical intervention, a set of specially designed screws with extended screw heads can be used in ordinary plating. These screw heads can be just subcutaneous, thus allowing the screws to be retrieved with only minimal incision. Alternatively, the screw heads can even be percutaneous (with risk of infection) for convenient retrieval. Such a system will have at least the following advantages: (A) Compared to external fixation systems, it is more convenient functionally and appealing cosmetically. (B) The screws can be retrieved one pair at a time in various stages of healing. It not only facilitates the increase of bone loading as the fracture heals, but also allows the screw-holes to be filled by new bone tissue before the next pair of screws are removed. However, such an idea is not without its biomechanical concerns: How effective GSR is in lessening of the stress-shielding effects, and how stiff the fracture union has to be before GSR can safely proceed. This report attempts to provide some preliminary answers to these issues.

METHODS

A simplified 2D finite element model was set up using ANSYS-PC/ED (Fig. 1). The model consisted of 99 quadrilateral isoparametric plain strain elements with a total of 272 degrees of freedom. The diaphysis of the bone is approximated by a rectangular beam with equivalent bending rigidity. A 2.7 mm thick and 12 mm wide stainless steel plate was connected to the bone only through three 3.5 mm diameter screws on each side of the fracture site. A clearance of 0.1 mm was otherwise assumed between the plate and the bone. For elements representing the screws in the bone, the element Young's modulus was modified based on equivalent axial stiffness to reflect the fact that not the entire width (12 mm) of the element was occupied by the screw (3.5 mm Dia.). A combined loading of 1500 N/m compressive force and 10 N-m/m bending moment was applied to one end of the diaphysis. Symmetry about the fracture site was assumed. Three situations were studied with each stage of healing, namely, with all screws in, with the outermost pair (C) retrieved, and with the two outer pairs of screws (B & C) retrieved. The Young's modulus for bone was 18.5 GPa, while that for stainless steel was 200 GPa. To simulate the healing process, the Young's modulus for the healing union was assumed to be 0.01, 0.1, and 1 of the normal bone. A Poisson ratio of 0.3 was assumed throughout.

RESULTS

This simple 2D FE model predicted many basic trends of the behavior of the plate-screw fixation system[2]. In the initial healing stage, as long as the fracture gap was still open, the connection at screw A was most highly stressed, screw C came second, and screw C sustained the least stress. As the healing progressed, the stresses in screw A was sharply reduced by an order of magnitude. As soon as the fracture site closed and the union about 1/100 as stiff as the normal bone, most of the load transfer between the plate and the bone occurred at screw C. As the fracture union became stiffer, the bending stresses in the plate right above the facture site were also drastically reduced. This pattern apparently was not significantly altered by subsequent GSR.

Removal of screw C after the fracture gap closed would shift the major load transfer site to screw B. Allowing the bone tissue in the region between screws B and C to sustain a more normal stress pattern (Fig.2). With the fracture union stiffness as low as 1/10 of the normal, removing screw C would not subject the middle pair of screws to stress values significantly higher than those in screw C initially - not more than 1.5% for the maximum shear(Fig.3). Both the plate stresses right above the fracture union and the axial displacement of the fracture union did not seem to be altered much at all compared to the corresponding state before screw removal. These results suggested that it was biomechanically feasible to remove the screw C when the fracture union became at least 1/10 as stiff as the normal. Removal of both screws B and C (i.e. with only screw A remaining) did not seem to unduly compromise the stresses in screw A. Pushing the time of retrieving screw C earlier to the point when the fracture union stiffness was only about 1/100 of the normal would subject screw B to maximum shear about 7.5% higher than that at screw C initially. Besides this concern, there seemed to be no other contra-indication based on the results of the present simplified model.

DISCUSSION AND CONCLUSION

The present 2D simplified FE analysis seemed to suggest that GSR would not subject the remaining screws to stresses significantly higher than the values initially for the outer screws, as long as the fracture union became at least 1/10 as stiff as the normal bone tissue. This conclusion needs to be further checked by a more refined 3D model, since it has been reported that 2D analyses were inadequate for accurate prediction of screw stress[3]. However, the results in this study should still generally depict the pattern of change in stress distribution as GSR proceeds. The exact synchronization between GSR and the healing process needs to be further defined by animal experiments. The present model did not account for any frictional contact between the plate and the bone surface, which should represent the lower limiting case for the stress-shielding effect. It was thought that if significant reduction of the stress-shielding effect can be demonstrated in this model, such reduction should only be more substantial if frictional contact is included.

ACKNOWLEDGMENT

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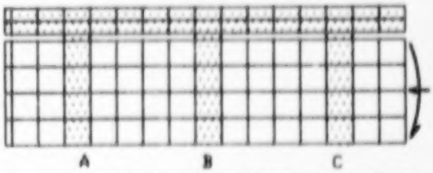

FIG.1 FE MESH SHOWING SCREW POSITIONS.

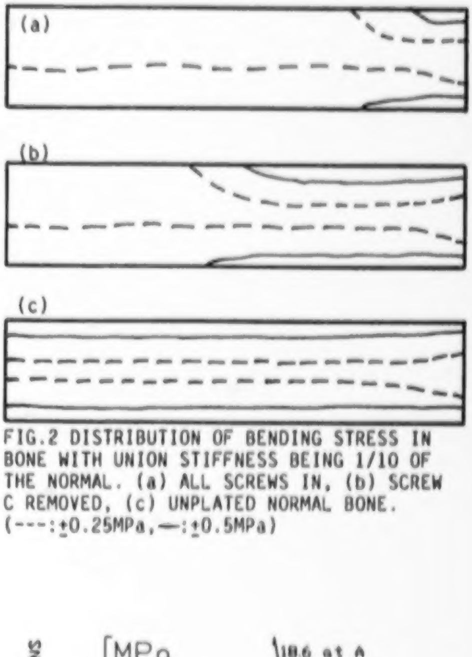

FIG.2 DISTRIBUTION OF BENDING STRESS IN BONE WITH UNION STIFFNESS BEING 1/10 OF THE NORMAL. (a) ALL SCREWS IN, (b) SCREW C REMOVED, (c) UNPLATED NORMAL BONE. (---:±0.25MPa, —:±0.5MPa)

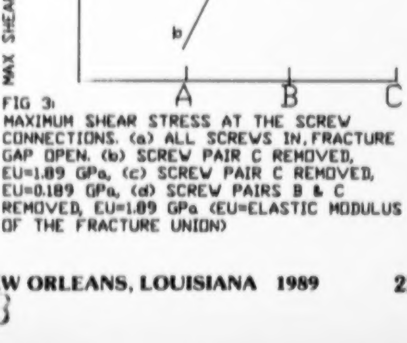

FIG 3:
MAXIMUM SHEAR STRESS AT THE SCREW CONNECTIONS. (a) ALL SCREWS IN, FRACTURE GAP OPEN. (b) SCREW PAIR C REMOVED, EU=1.89 GPa, (c) SCREW PAIR C REMOVED, EU=0.189 GPa, (d) SCREW PAIRS B & C REMOVED, EU=1.89 GPa (EU=ELASTIC MODULUS OF THE FRACTURE UNION)

26.4

USING PRESSURE EVALUATIONS TO AID IN THE DESIGN OF PRESCRIPTION FOOTWEAR

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ABSTRACT

In order to find an effective means of relieving forefoot stress under the feet of patients who can not feel these stresses, an objective means of pressure quantification needs to be used. These studies focused exclusively on the outer sole shape as a means of reducing forefoot stress during gait. Capacitance pressure transducers were placed between the foot and shoe to quantitate the pressure values. Certain sole designs were found to be more effective at reducing stress

INTRODUCTION

Previous studies have shown that rigid-soled shoes with a curved (roller, Fig. 1) or angled (rocker, Fig. 2) design of the outer sole shape can be effective in relieving pressure under the front of the foot (7,8). Several different shapes have been described in the literature (8,9). None of these styles have been universally incorporated into shoe modification. This may be due to a lack of clear objective evaluation of the precise construction of these modification and a quantification of the most effective shape.

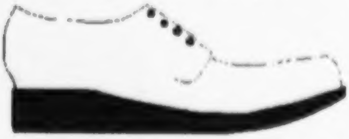


Fig. 1. The roller style sole forms a curve over which the foot rolls as the heel is lifted.

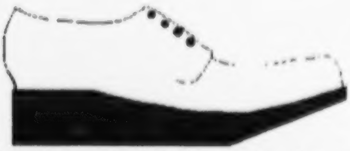


Fig. 2. The rocker style forms a single fulcrum of rotation below and behind the metatarsal heads.

METHODS

Pressures were measured using capacitance pressure transducers. These were placed under bony prominent areas which had been previously identified as the sites most frequently ulcerated in insensate feet. Four Hercules F4-4R Orthoflex Transducers were used to simultaneously record each step. These were connected to a model 4824SP four-channel chart recorder. The F4-4R transducers display linearity within 1% with 1% maximum hysteresis and a maximum 0.5% sensitivity shift with temperature changes. They are 2 mm thick and 19 mm in diameter. The transducers were calibrated to insure proper performance before and after each subject was tested.

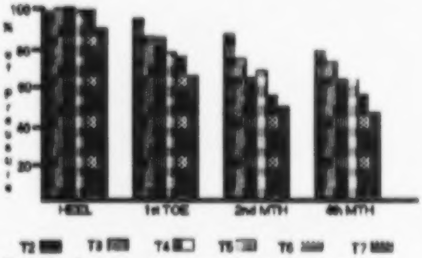
Study I shoes were tested with the following soles:
T1 - unmodified shoe
T2 - the same shoe sole was made rigid
T3 - the rigid sole roller was curved on a 23 cm. radius
T4 - a 15 degree rocker was cut into this sole
T5 - an 18 cm. roller was made on the sole
T6 - a 20 degree angle rocker was cut into the sole
T7 - a rocker of 30 degrees was added to the sole

The toe spring was maintained at the same level on all shoes.

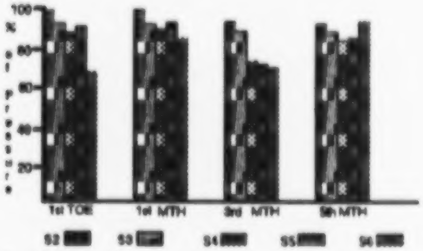
Study II had 20 subjects walk 200 feet in 6 different sole designs (11). The transducers were placed under the first interphalangeal joint and the first, third and fifth metatarsal heads. The sole modifications were:
S1 - unmodified shoe
S2 - the sole was curved on a radius of 125% of the shoe length
S3 - the sole was curved on a 75% radius with take-off point at 60%
S4 - the sole was curved on a 75% radius with take-off point at 50%
S5 - the sole was curved on a 60% radius with take-off point at 50%
S6 - a rocker of thirty degrees was added to the sole

RESULTS

In the following bargraphs T1 and S1 mean pressures were assigned a value of 100%. All subsequent changes are recorded as they relate as percentage of the mean pressure change relative to the unmodified shoes.



Graph 1. Rocker styles were more effective than rollers at relieving forefoot stress. Rockers with higher angles and rollers with smaller radii were the most effective.



Graph 2. The higher rocker was still more effective at relieving stress than rollers except under the fifth metatarsal head. Moving the "take-off" point posterior improved the performance of the sole.

DISCUSSION

In both studies the rocker style with a 30 degree angle was most effective at relieving forefoot pressure. Clinically it has not been readily accepted by patients. This is usually due to a feeling of instability as the heel is lifted during each step. This is clinically beneficial because the patient feels required to drop the opposite foot for balance thereby reducing pressure on the involved side.

In Study II we attempted to quantify the ideal curve for the more readily accepted roller design. Curvatures with a smaller radius and that begin to roll at 50% of the shoe length were more effective at reducing forefoot pressure. The subjects stated during the trials the roller soles felt the same as the unmodified shoe during ambulation.

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27.1

A FIBER OPTIC FORCE SENSOR FOR AUTOMATED SEATING DESIGN

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Abstract

Two fiber optic force transducers have been developed for use in an automated seating system. The first is an intrinsic microbending sensor and the second is an extrinsic diffuse reflective sensor. The two sensors have been compared and evaluated for use in the system.

Introduction

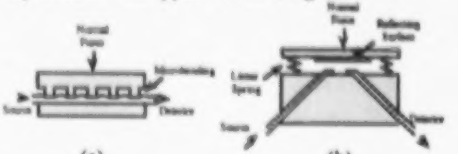
The measurement of forces acting on soft tissue at the body-cushion interface of seated individuals is believed to be essential in the design and assessment of contoured seat cushions. An automated contour design system has been proposed in which contour shape is controlled using force at the contour-body interface as feedback. This system will contain on the order of 150 position actuators to control the shape of the contour, with force sensors located on each actuator. The work presented in this paper concerns the development of a suitable force transducer for this application.

Advantages of Fiber Optics

Several types of force transducers were considered for this application.[1] Fiber optic sensors were chosen because they have three advantages over more conventional force transducers. The first and most distinguishing characteristic of fiber optic sensors is that many individual sensor outputs can be multiplexed to a small number of detectors and signal conditioning circuits. Force transducers such as strain gages require a signal conditioning circuit for each sensor. In a system which requires a large number of sensors, the cost of the signal conditioning circuits can become prohibitive. The second advantage fiber optic sensors have over conventional force transducers is electro-magnetic noise immunity. The environment in which the sensors must operate will contain significant noise generated by electric motors used to shape the contour. Immunity to this noise is an important feature of the force sensing element. The third advantage of fiber optic sensors is physical dimension. The small size of a fiber optic sensor allows it to be located very close to the actual probe-cushion interface in the seating system. This proximity minimizes error associated with approximating the force acting normal to the contour at this interface.

Sensor Configurations

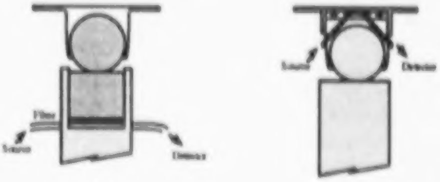
Two types of fiber optic sensors have been evaluated for use in the automated contouring system. The first type is known as a microbending force transducer. As light travels through the core of a glass fiber, any irregularity in the core-cladding interface results in loss of light due to the changed geometry of the fiber. This loss of light in the fiber is then directly related to the intensity of the signal measured at the receiving end of the fiber. The principle of a microbending sensor is to induce irregularities in the core-cladding interface proportional to an applied force. (Fig. 1a)



(a) (b)

Figure 1 : Sensor Principle (a) Microbending Sensor (b) Reflecting Sensor

The second evaluated force transducer, a diffuse reflective sensor, guides light by an optical fiber from a source to the location of the sensor. At the sensor location, the light leaves the fiber to be reflected off an external surface. A second fiber collects the reflected light and guides it to a detector. (Fig 1b) The intensity of light gathered by the second fiber is related to the distance from the ends of the fiber to the reflecting surface. Hence, by measuring the change in intensity, the distance to the surface can be accurately approximated. Similar fiber optic sensors have been successfully implemented as high accuracy displacement transducers.[2]



(a) (b)

Figure 2 : Sensor/Probe Configurations (a) Microbending (b) Reflecting

Microbending sensors in general are of questionable use in practical situations. Although they are simple in concept and design, they suffer several shortcomings related to the nature of the fiber itself. Small diameter glass fiber (50-150 mm core) is surprisingly durable when jacketed by flexible material, however, the fiber becomes extremely fragile with the jacket removed. It would not be feasible to use an unjacketed fiber in a force sensing environment. Therefore, since the jacket must remain intact in the sensor, the deformation characteristics of the jacket itself become important variables in the sensor response. In the experimental results shown in Figure 3a, it is believed that the majority of the hysterisis effect is due to the viscoelastic properties of the fiber jacket.

Another drawback of the microbending sensor is that it is very sensitive to off axis loading. For this reason, the sensor must be configured such that it is affected only by forces normal to the ridged surface. Such a restriction prohibits the sensor from effectively being mounted directly at the probe-body interface. That in turn limits the effectiveness of the sensor because the output will be related to the force normal to the contour by the cosine of load angle minus the mechanical loss of the toggle assembly. This effect was shown experimentally with strain gages in reference [1]. A sensor configuration which directly measures the force normal to the contour would be more desirable.

The probe/sensor configuration for the reflective sensor is shown in Fig. 2b. Although slightly more complex than the microbending configuration, the reflective sensor may be located above the pivoting toggle, permitting a direct measurement of the force normal to the probe-tissue interface.

Experimental Results

Shown in Fig. 3 are typical calibration curves for both the microbending and reflective sensors. Table 1 lists the important statistical information for both curves.

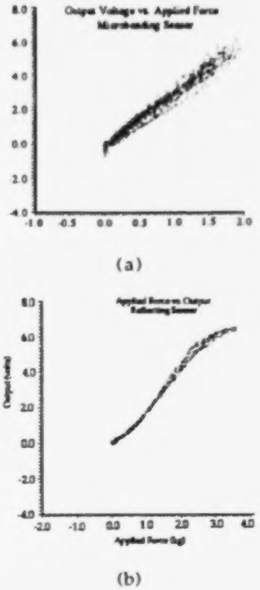
Microbending Sensor:	
Range (full scale)	0.0 - 2.0 kg
Linear LS Fit	y = 2.98x - 0.09
Std Dev.	0.272 (4.5% FS)
Reflecting Sensor:	
Range (full scale)	0.0 - 3.6 kg
Linear LS Fit:	y = 2.12x - 0.20
Std Dev.	0.279 (4.3% FS)
Cubic LS Fit:	$y = -0.26x^3 + 1.24x^2 + 0.66x + 0.01$
Std Dev.	0.128 (1.9% FS)
Range (reduced)	0.4 - 2.75 kg
Linear LS Fit:	y = 2.40x - 0.60
Std Dev.	0.15 (2.3% FS)

Table 1 : Statistics of Calibration Curves

Discussion and Conclusions

A microbending sensor is simple in design. Questionable durability, sensitivity to off-axis loading, and fiber jacket hysteresis combined with unjacketed fiber fragility, however, make it less desirable than other sensor types. In its favor, the small-diameter glass fiber used in a microbending sensor makes large ratio multiplexing possible. This is important due to the large quantity of sensors required and the high cost of signal condintioning circuits.

A reflecting sensor is a mechanically more complicated yet feasible design. The reflecting sensor is also apt to be more reliable than the microbending due to the lack of mechanical strain on the fiber. Instead, strain is placed on a compliant material such as a spring. The use of large diameter (500-1000 mm) plastic fiber in this sensor reduces the need for high cost precision coupling yet limits the multiplexing cabability.



(a)

(b)

Figure 3 : Calibration Curves (a) Microbending (b) Reflecting

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Acknowledgment

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27.2

COMPUTER AIDED MEASUREMENT AND FABRICATION OF CONTOURED BODY SUPPORTS

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INTRODUCTION

The necessity of providing customized seating supports for the wheelchair-bound individual has been recognized for quite some time. Without proper support, postural complications and pressure sores often result. However, available technology has not been able to sufficiently meet the demand for the timely delivery of low cost seating systems.

Recent research at the Cleveland Clinic has resulted in a method of measuring body contours and fabricating customized seating supports. Previous work has shown that suitable body supports can be constructed by measuring transverse contour slices from a dilatancy molding system. These contours are used to cut ethafoam blanks which are then sandwiched together to provide a three-dimensional support system.

Recent research has focused on the development of a computer-controlled system for sensing seated body shapes and generating corresponding supports. This system uses an electronic sensor for measuring the body shape. The acquired data is used to cut the foam blanks by means of a numerically controlled cutter. Data collection, modification, and cutting are all controlled by an IBM PC/AT.

METHODS

A standard dilatancy molding system is shown in Figure 1. Both the seat and back portions of the system consist of a rubber bag filled with plastic beads. A vacuum line is connected to each bag which allows the pliability of the support surfaces to be varied.

When a patient is placed in the molding system, the therapist is able to modify the support surface to provide the optimal fit for the patient's specific needs. Once the final shape has been established, all of the air is drawn out of the bags leaving a rigid mold of the patient's body shape.

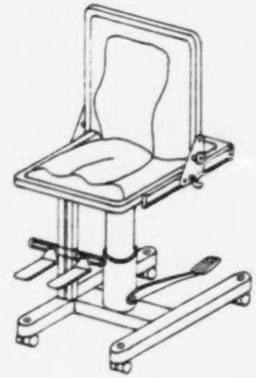

Figure 1. Dilatancy Molding System

An electronic sensor has been developed to record the body shape established in the dilatancy molding system. Figure 2 shows the electronic sensor mounted on the dilatancy molding system. The sensor uses 32 linear potentiometers placed side by side. Aluminum shafts link the potentiometers to the body contour surface. The physical position of the shaft is thus represented by the voltage level at the potentiometer output. The respective voltages are sampled and converted to a digital form by an analog-to-digital converter. This information is then stored in computer memory for subsequent operations. The potentiometers are spaced at one-half inch intervals. The entire array of potentiometers can be moved longitudinally on guides supported by the molding frame.

Once the contour data has been acquired, the therapist can view and modify the data through the use of a specially designed computer graphics program. Figure 3 depicts the display of the contour data. Each recorded slice can be viewed in the top window of the display. The lower window displays a longitudinal view of the contour taken through the point specified by the cursor in the top window. Each point on the contour can be selected and modified as the therapist desires.

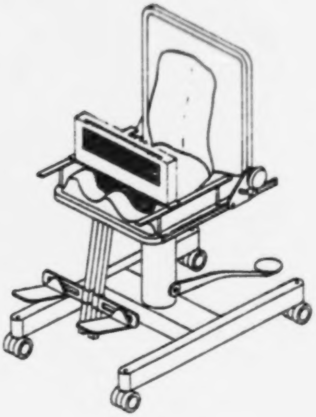

Figure 2. Electronic Contour Measurement System

When a satisfactory contour has been established, the support system can be cut from ethafoam blanks. The graphics software is used to drive a numerically controlled cutter which consists of a two-axis positioning table and a fixed cutting tool. Each axis of the table is driven by a stepper motor with a resolution of 0.005 inches. Each blank is inserted into the cutter and the corresponding curve is cut. When the blanks have been finished, they are sandwiched together to provide a customized three-dimensional support system.

CONCLUSIONS

The results of this work have shown that a customized support system can be fabricated within two hours following the molding of the patient's body shape. Previous methods have required delays of from one to two months. In addition to the rapid turn around time, modifications to the support system can be made quite easily by replacing existing foam slices with modified slices. Once the actual support has been fabricated, a polyurethane liner is added to provide additional pressure relief. A vinyl cover is then vacuum-formed over the support to provide resilience.

Subsequent research will involve the fabrication of body supports from a single block of ethafoam. In addition, the possibility of establishing several clinical sites is being investigated. Patient data will be acquired at these satellite locations and the information will be transmitted to a centralized fabrication facility. This system promises to provide a greatly improved approach to the delivery of customized body supports.

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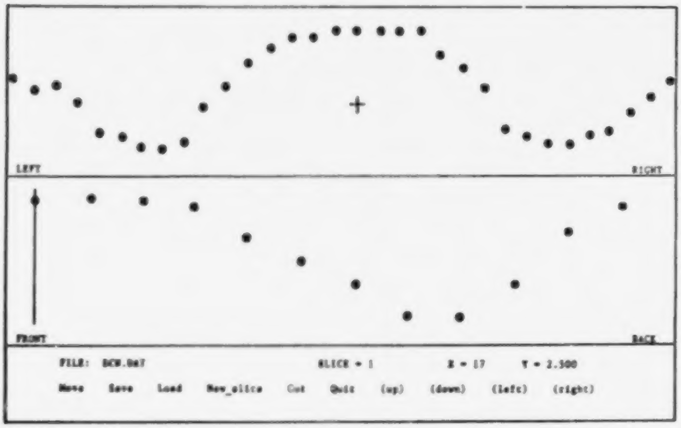

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Figure 3. Interactive Computer Graphics Display

27.3

UVA CUSTOM CONTOURED SEATING SYSTEM
TECHNICAL AND CLINICAL EVALUATION

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ABSTRACT

A cost-effective method utilizing CAM technology was developed to fabricate custom contoured seat cushions(CCSC). This paper presents the design, prescription, and clinical evaluation of the CCSC during the past 2 years for improving seating support for WC users. Future improvement of the system and the potential for clinical application are discussed.

INTRODUCTION AND BACKGROUND

Many disabled individuals need appropriate cushions to provide protection from tissue breakdown, and for adequate posture and stability in WC seating. In the past decade, seating & positioning have been an important consideration for any non-ambulatory child or adult. One major area is the design, prescription and assessment of body support for maximum function with minimum secondary deficits and body deformities. Recently, a tremendous growth in the number of techniques, facilities and practitioners has contributed to body support for all types of disability. In spite of these advances, three major challenges remain - the continued incidence of decubiti, the need to produce seating systems quickly and economically and the optimization of mobility and function.

Numerous WC cushion designs are available commercially. Most of them are expensive, none has been found to match the needs of every disability & cushion selection for each individual is seldom simple. Recently, the use of custom molded or contoured devices has found increasing clinical acceptance. But, the techniques (foam-in-place, foam-in-box & vacuum consolidation) require skilled technicians and labor intensive fabrication. Additionally, these usually result in systems that are heavy and require tedious modification.

Support surface and material property are important in determining the load transfer to soft tissues & skeleton. Theoretically, tissue distortion and pressure can be optimized by matching support surface and cushion's material property to body contour and tissue compliance. Based on this concept, UVA REC has designed a contour gage & adjustable fitting seat to study the biomechanics of tissue-cushion interface contour & pressure & body positioning of the SCI on WC cushions. Recently, an automated system is developed to fabricate the CCSC quickly & economically. Using different foams, this system is able to prescribe & deliver a CCSC in a near real-time operation. This study is designed to develop and evaluate customized contour cushions for use by the disabled. Applications can be made to the able-bodied.

METHODS

Adjustable Fitting System - angle adjustment (seat, back, leg, foot & forearm); linear adjustment (seat depth,leg length).

Contour Gage - forms the seat of the fitting system and consists of 64 probes in a 16" X 16" area to quantitate cushion indentation contour for seated persons on flat foams using linear potentiometers. After a client is properly seated & positioned, equilibrum contour data recorded through A/D convertors and a 3-D surface contour displayed on a PC within 1 minute.

Automated Foam Contouring System - is made of a CNC and an automated XYZ milling machine to contour an 18" X 18" area with max. depth of 3", and can fabricate a CCSC in 15 minutes with many types of foam (regular foam, T-foam & ethafoam) by following the measured contour.

IBM-PC - 16 channels of A/D with 12 bits for contour data collection, a serial port for directing the contour machining and a parallel port for printer. Software developed include data acquisition mode for 64 sample pts; editing mode for modification of the contour profile to improve asymmetric seating, pelvic obliquity, pressure relief, etc.; interpolating mode for data expansion from an 8 X 8 into a 33 X 33 array to provide better resolution (2" to 1/2" using Cubic Spline or Whittaker reconstruction) when carving the contour; displaying mode for 3-D contour graphs; & interfacing mode for communication between the computer, the CNC & the contour gage.

Foams - include 3", medium density (3.2 lb/cubic ft) and high resiliency foam (HR) with ILD ratings (11, 24, 32, 45, 55 & 70), viscoelastic and etha foams.

Oxford Pressure Monitor - Pressure at the sitting interface was measured by placing 24 transducers in the regions of both I.T. and 6 each in both thighs.

Cushion Coating and Cover - A waterproof coating (RTV 732 silicon) is applied to the surface of CCSC, and an elastic-type cover (Lycra Spandex on the top and nylon backpack material on the other sides) is used to preserve the contour & permit easy transfer. A hardboard is usually applied to reduce hammocking effect of sling seat.

Clinical Evaluation - A research team (UVA seating scientists, P.T. & O.T. of seating specialists), reviews subject's specified disabilities prior to prescription. Seat contours are measured after the client is properly seated and positioned. Modification of the contour profile is made to match the individual need, an acceptable contour is fabricated & the CCSC evaluated and compared to subject's current cushion. Preliminary pressure, balance, posture & repositioning evaluation are made; if acceptable, he/she is instructed to use the CCSC for a few days with skin checks. If subject's WC needs adjustment, it is done at this time. During the trial, ten clinical variables evaluated are pressure, transfer ability, balance, comfort, propulsion of WC, effect on spasticity & tone, posture and stability, skin reaction and pressure relief/repositioning. A long term evaluation up to 1 year will be performed.

Subjects - include disabled children & adults with SCI, CP, Myelo, MS, Polio, pain disorder & geriatric problems. The able-bodied are also included for the use of CCSC on their regular and car seats.

RESULTS

The results of 25 chronic & 5 acute SCI (C-4/5 to L-3) show significant pressure improvement when CCSCs are used. Generally, functional abilities, balance, posture alignment and comfort are often enhanced. The CCSC can be prescribed in 30 min. for those without severe deformity. In severe cases or flaccid paraplegia, another 30-60 min. are needed for contour modification.

For the other disabled groups, the system is able to manipulate quantitative contour data easily and effectively for design and prescription of suitable CCSCs on various foams. This indicates that the use of CCSC does indeed provide effective seating and better positioning for the subjects studied. Due to small # of subjects and less experience and knowledge in this area, further research is strongly suggested.

For able-bodied subjects, the use of CCSC demonstrates significant reduction in seating pressure with improved comfort. The results reveal the potential of Custom Seating to improve office & vehicle seats. More than 25 persons have used the CCSCs during the past two years. At least 6 people have used these constantly in their chairs and 4 people in car seats. They reported feeling more comfortable and experiencing less physical fatique during long trips of 6 or more hours of driving.

DISCUSSION

The contouring of foam improves the enveloping property & available support area. The contour gage is useful in quantitating seating interface contour for customized contour fabrication. Knowing the location of the probe in the sitting surface, localized modification of the contour profile can be scientifically & easily achieved to meet special needs: changes of contour deflection in one side for improving asymmetric seating or obliquity, increase of localized deflection to heal pressure sore & reduce another risks, and development of an abductor or adductor for proper positioning. It also allows for contour measurement on one foam and CCSC fabrication on another: contour measurement on HR-24 & CCSC fabrication on HR-45 for light weight persons, or the measurement on HR-70 & the fabrication on HR-55 for heavy persons or the flaccid paraplegic. Experience to date shows this approach provides a cost-effective method for customized cushion prescription to improve seating pressure, positioning, body stability and comfort.

Several problems encountered need to be improved: 1) improve the resolution (from 2" to 1") of contour gage for shape measurement, particularly for the child or the severely deformed; 2) design an adjustable locking mechanism on each probe which can be easily used for positioning and contour modification; 3) develop an effective back contour sensing system; 4) study the biomechanics of cushion material & lifespan of CCSC; 5) continue to collect baseline data on disabled populations & develop clinical guidelines for CCSC prescription.

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27.4

A COMPARISON OF FORCE TRANSDUCERS SUITABLE FOR AN AUTOMATIC BODY SUPPORT CONTOURING SYSTEM

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Introduction

The theory of elasticity applied to the problem of determining the pressure between two bodies in contact predicts that interface pressure for a given load will be minimized when the two bodies have complementary surface shapes [1,2]. This prediction has led to a search for a method to manufacture custom contoured body supports for wheelchair-bound individuals with the expectation that the incidence of pressure sores in these individuals will be greatly reduced [3].

The actual derivation of a complementary contour of human tissue is difficult since the tissue deforms during measurement. A second problem arises from the fact that the contact stress theory is based on elastic homogeneous solids which the human body certainly is not. Therefore, an active contour gage constructed of adjustable pressure probes has been proposed to measure interface pressure and actively reconfigure itself to reduce this pressure. This paper compares force transducers, including a new fiber optic pressure transducer, available for use in this contour gage.

Any useful transducer would need the following performance characteristics:

1. Well defined, high sensitivity input vs output characteristic.
2. Force resolution of less than 40 grams,
3. Fast response, preferably less than 0.2 seconds,
4. Minimal errors due to noise, drift, or hysteresis.
5. Ability to be located on a moving probe.

These qualities were specifically considered in testing the transducers compared in this paper.

Theory and Test Results

Transducers designed using force sensitive resistors or FSR's [4], strain gages [5], and fiber optics as their sensing element were considered to provide the best solution to the transducer problem. Prototype transducers were fabricated and their static and dynamic characteristics evaluated. FSR's were removed from consideration due to hysteresis effects, non-linearities and other problems associated with requirements peculiar to this particular use.

Strain Gages

Strain gages are commercially available devices whose resistance changes in relation to their state of strain. They are very versatile in that many physical conditions can be measured by their proper application. One such application is the measurement of thrust on a circular shaft. Murray and Stein describe how thrust measurement may be accomplished independently of bending and torsion. The strain gage force sensor also incorporates an instrument amplifier to boost the relatively weak signal from the strain gage bridge and a 3 pole bessel filter with a 2 Hz cutoff frequency to attenuate background noise. The transfer function of the gage-amplifier-filter system used is given by,

$$G_{Sensor} = \frac{1.704}{0.524 \times 10^{-3}s^3 + 0.039s^2 + 1.2097s + 15} \quad (1)$$

where s is the Laplace operator.

Tests of this sensor show a linear response to applied force and a one-to-one relationship can be established for all sensors in the system at large. A one-to-one relationship is important so that, in any control algorithm, multiple sensors may be assumed to have the same transfer function characteristics. These sensors drift at a rate of 800 μV, equivalent to 3.2 grams per minute. They also exhibit a relatively slow response time, 500 milliseconds, as would be predicted by Equation 1.

Fiber Optic Pressure Transducers

Two types of fiber optic sensors have been developed and evaluated for use in the contour gage [7]: an intrinsic microbending sensor and an extrinsic diffuse reflective sensor. The fiber optic sensors have several special characteristics which make them well suited for this application. First, the use of light for signal transmission allows for high ratio multiplexing to the signal conditioning circuits, provides electro-magnetic noise immunity, and a fast response time. Furthermore, the physical dimensions of the sensor will allow the force measurement to be taken near the probe-body tissue interface.

The microbending sensor is an intrinsic sensor in that the fiber itself is the active element of the sensor, as well as being used for signal transmission. The reflective sensor, on the other hand, is extrinsic in that the fiber is used only for signal transmission and the active sensing element is external [8]. While the intrinsic nature of the microbending sensor provides for a simple and compact sensor design, the need for a custom jacketed fiber and concerns over the long term reliability discouraged further development. The reflecting sensor retains the primary advantage of the fiber optics, optical signal transmission, yet promises to be more reliable than the microbending sensor.

A prototype of the reflecting sensor has been fabricated and is described in reference [7]. Due to the low noise characteristic of the sensor, the signal conditioning circuit was designed with a relatively high 7 msec response time. With the use of time division multiplexing, this will allow an array of 120 sensors to be updated at a rate of $2n$ Hz, where n is the number of photo detectors used. The actual response of the sensor with respect to a varying force will be dependent on the response of the active element, a linear spring. Data from the first prototype shows that with a full scale range of 0 to 3.6 kg, the standard deviation of a linear least-square fit is 4.24% FS and a cubic least square standard deviation is 1.95% FS. Over the range 0.4 to 2.75 kg the linear least square standard deviation is 2.3% FS. Hysteresis of the spring contributes the greatest amount of error. Further development of the sensor promises to reduce this error.

A Design Consideration

The location of the sensor on the adjustable probe needs to be considered during design. If the probe is capped with an assembly that could swivel to remain normal to the body tissue, such as a toggle, a sensor located in the probe itself would not measure the actual normal force but a force dependent on the cosine of the load angle. Figure 1 demonstrates this effect with measured values obtained from a strain gage sensor.

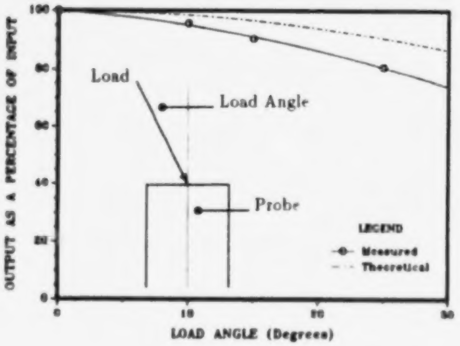

Figure 1: Effect of Off-Axis Loading

A sensor that could be located in the toggle portion would obviously be advantageous. Unfortunately, the strain gage sensor does not lend itself to use in this location. The reflecting type fiber optic sensor, however, will probably be able to meet this demand. In either case, the real errors associated with off-axis loading must be considered in the design and use of the system so that they may be minimized and their impact on results fully understood.

Conclusions

The strain gage force sensor is used in the current model system. A large number of sensors, approximately 150, will be required in the full scale contour gage. This need, coupled with the cost of the electronics associated with each strain gage sensor, continues to fuel the search for an alternative device such as the fiber optic sensor discussed in this paper.

The multiplexing capability of fiber optic sensors is their biggest advantage. The significance of this advantage is dependent on the final multiplexing ratio which in turn depends on the active area of the detectors and the diameter of the fiber used. The possibility that the fiber optic sensor could be placed on the toggle portion of the probe provides additional incentive for its development.

Fiber optic sensors may finally provide clinicians with an accurate interface pressure measurement tool for use in their diagnostic work.

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27.5

THE INFLUENCE OF PHYSICAL CHARACTERISTICS ON SEAT CONTOURS

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ABSTRACT

Seat contours were measured and studied to determine the influence of physical parameters on contour characteristics. Body weight, intertrochanteric width and skin tone were all found to affect contour depth, surface area and displaced volume. Skin tone exerts a greater influence on contour as foam stiffness increases.

INTRODUCTION

Many types of wheelchair cushions have been developed to reduce the occurrence of pressure sores. Recently, tissue distortion has been mentioned as an important indication of tissue damage (3,5). Theoretical and empirical experiments (2) indicate that a compliant contoured cushion may be effective in lessening tissue distortion of the buttocks in a seated posture. Recent studies found beneficial postural and pressure effects of custom contoured foam cushions and suggest further study into their use (4). This project was designed to study the effect of certain subject characteristics on seat contours. Understanding this relationship would further explain the load transfer from the buttocks to a cushion. The results of this project could be used in the design and prescription of custom contoured cushions (CCCs) to reduce tissue distortion and produce a more uniform pressure distribution.

PROCEDURE

An adjustable positioning system has been developed to study body position, body contour and pressure distribution on various cushion surfaces (3). Contour at the buttock-cushion interface is measured by the contour gage which consists of 64 probes and forms the seat of the positioning system. Deflection data is collected using a computer and once reviewed, is used to fabricate a CCC. The automated contouring system consists of two components - a computerized numerical controller or CNC and an automated XYZ milling machine (1).

Seat contours were recorded for 17 persons, 11 SCI and 6 able-bodied individuals. Subjects were transferred onto the positioning system and after properly seated, deflection data was measured and a custom contoured cushion was fabricated by cutting out the measured contour in foam. Each subject was studied on two types of 3", medium density (3.2 lb/ft^3), high resiliency foam (HR) with respective ILD ratings of 45 and 55 lbs.

Contour characteristics were represented by three numerical quantities, maximum contour depth (DEPTH), surface area (SAREA) and displaced volume (DISVOL). Three variables were used to describe the subjects. Intertrochanteric distance (TROCH) was used as a measure of pelvic width. Body weight (WGT) was used to represent the load on the cushion. Disability level (DISLEV) was intended as an index of buttock stiffness and represented the three general classifications of tone- spastic, flaccid and normal. Subjects were queried about their lower extremity tone and were assigned to 3 groups: 'no SCI', 'C4-T4' and 'T9-L3'. Multiple regression equations were calculated for each contour characteristic by entering all three subject characteristics. Equations were formed from data for both the HR45 and HR55 foams.

RESULTS

The results of the multiple regression and correlation analyses are shown in Tables 1 and 2. In the regression analysis, $p<.05$ was accepted as statistically significant. For the HR45 foam, more than 55% of the observed variability in DEPTH, SAREA and DISVOL can be explained by the three subject characteristics. For the DEPTH equation, TROCH, WGT and DISLEV are all significant predictors. The SAREA equation shows WGT and TROCH are significant predictors. Only WGT seems to significantly predict DISVOL. The HR55 foam exhibits a strong linear relationship ($R=.784$) between the subject characteristics and each contour description. DISLEV is the only significant predictor in the DEPTH and SAREA equations. In the DISVOL equation, both DISLEV and WGT are significant predictors.

DISCUSSION

The regression equations differ greatly for each foam. The HR55 equations seem to reflect a stronger linear relationship between contour description and subject characteristics. This may occur because contours on the softer HR45 foam are influenced by a number of different factors of which only a few are entered here. Together, body weight, intertrochanteric distance and disability level become better predictors of contour as foam stiffness increases.

In general, all three contour descriptions are correlated. Since depth, surface area and displaced volume are all simple quantifications of a contour shape, the high intercorrelations are not surprising. However, each contour description offers something different to the biomechanical analysis of the seated posture. Maximum contour depth may give some indication of how load is transferred. A deep indentation denotes that high loads are being absorbed by the cushion and may indicate a bottomed out condition. Displaced volume is a measure of the volume reduction which occurs during compression of foam. The ability of foam to decrease in volume allows it to have a good enveloping property. It is the enveloping of a material that allows the cushion to wrap around the buttocks, produce side loading and improve the weight distribution. Given a certain load, one way to lower pressure distribution is by increasing the area of contact. The available surface area of a loaded CCC is greater than that for a flat foam.

The overwhelming difference between the results of the two cushions tested is the predictive ability of disability level. On the HR45 foam, DISLEV was a significant predictor of contour depth only, but on the stiffer HR55 foam, DISLEV was the strongest predictor for maximum depth, surface area and displaced volume. DISLEV was intended to represent the levels of skin tone; therefore some conclusions can be drawn concerning the relationship between foam stiffness and skin tone. As tone decreases, the area of load transferral decreases. A person with normal tone can transmit load over a greater area; and on a stiff cushion, regardless of body weight, he/she will not deform a cushion as much as someone with flaccid tissue. In brief, all three of the subject characteristics, body weight, intertrochanteric distance and disability level are important predictors of contour in soft foam. However, as foam stiffness rises, disability level becomes such a strong predictor, that the other two appear less powerful.

In conclusion, the results indicate that seat contours are affected by several subject and cushion characteristics. These factors all influence the method of load transferral from the buttocks to cushion. This project helped identify the influencing variables and should help direct further study into contoured seating systems for the positioning needs of persons exhibiting all types of disabilities.

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TABLE 1 Multiple Regression and Correlation Results
HR45 Foam

Dependent Variable	Multiple R	R^2	Independent Variables	Beta	T	Sig T
DEPTH	.810	.66	DISLEV	.712	4.25	.0009
			TROCH	-.598	2.60	.0194
			WGT	.573	-2.66	.0220
DISVOL	.805	.65	DISLEV	-.143	-.842	.4152
			TROCH	-.426	-1.88	.0833
			WGT	1.03	4.61	.0005
SAREA	.749	.56	DISLEV	.272	1.43	.1738
			TROCH	-.645	-2.55	.0244
			WGT	.948	3.80	.0022

Correlations: significance * - .01 ** - .001

	DEPTH	DISVOL	SAREA	WGT	TROCH	DISLEV
DEPTH		.526	.812**	.285	-.038	.661
DISVOL			.844**	.717**	.235	-.077
SAREA				.556	.061	.271
WGT					.676*	.163
TROCH						.242

TABLE 2 Multiple Regression and Correlation Results
HR55 Foam

Dependent Variable	Multiple R	R^2	Independent Variables	Beta	T	Sig T
DEPTH	.892	.79	DISLEV	.894	6.94	.0000
			TROCH	-.225	-1.30	.2152
			WGT	.214	1.26	.2305
DISVOL	.916	.84	DISLEV	.687	6.00	.0000
			TROCH	-.089	-.583	.5699
			WGT	.574	3.81	.0022
SAREA	.904	.82	DISLEV	.850	6.94	.0000
			TROCH	-.114	-.697	.4984
			WGT	.301	1.87	.0847

Correlations: Significance * - .01 ** - .001

	DEPTH	DISVOL	SAREA	WGT	TROCH	DISLEV
DEPTH		.864**	.969**	.208	.136	.875**
DISVOL			.931**	.626*	.465	.759**
SAREA				.363	.295	.872**
WGT					.676*	.163
TROCH						.242

27.6

THE USE OF CONTOURED FOAM TO REDUCE SEAT INTERFACE PRESSURES

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ABSTRACT

Seat contours were measured and cut out in foam to obtain custom contoured cushions. Pressure and contour characteristics were compared on flat and contoured foam. Sitting on a contoured cushion results in less interface pressure. This decreased sitting pressure can be explained by differences in foam deflection and buttock enveloping between flat and contoured foam.

INTRODUCTION

Wheelchair users often spend 12-16 hours a day sitting while performing daily activities. Maintaining a seated posture for a long period of time requires special seating support especially for SCI persons and others with insensate skin. One major problem which has plagued SCI individuals has been the formation of decubitus ulcers. Externally applied pressure has been identified as a contributing factor of tissue trauma. Recently, tissue distortion has been mentioned as an indication of tissue damage (3,4). These two risk factors are related because distortion is a result of external forces being exerted on soft tissue. Theoretical and empirical experiments (2) indicate that properly fitted contoured foam would improve the pressure distribution through a decrease in damaging normal and shear pressure while increasing the non-distorting hydrostatic pressure. The basis of this research is to validate the theory that contouring a cushion to match the shape of the buttocks will result in a safer sitting surface. A biomechanical analysis of the buttock-cushion interface will help explain how contoured foam accepts load from the body and can be applied to the development of customized contoured foam cushions for use by the disabled community.

PROCEDURE

An adjustable positioning system has been designed to study body position, body contour and pressure distribution (3). A contour gage, consisting of 64 probes forms the seat of the positioning system to measure seat contours. The deflection of each probe is measured and used to fabricate a custom contoured cushion. The automated foam contouring system (1) consists of two components - a computerized numerical controller, or CNC, and an automated XYZ milling machine.

Eleven persons with spinal cord lesions (C5-L3) were studied. All the subjects were measured on two different 3", medium density (3.2 lb/ft^3), high resiliency (HR) foams with respective indentation load deflection (ILD) ratings of 45 and 55 lbs. Pressure distribution was measured by a 24 point transducer arranged in a 4 1/2" x 8 1/2" rectangle. The transducer was centrally placed in the region under the ischial tuberosities. Mean pressure and standard deviation for these points were studied. Mean pressures were analyzed using a two factor, repeated measures ANOVA. Foam stiffness (45 and 55 ILD rating) and cushion shape (flat and contoured) comprised the two factors. Therefore, each person's pressure distribution was measured on four cushions, flat HR45, contoured HR45, flat HR55 and contoured HR55. The contour gage measured the initial deflection of flat foam. A custom contoured cushion was cut out to match the measured contour. The CCC was then placed back on the contour gage to determine further deflection of the CCC. This 2nd contour measurement allowed analysis of how a CCC is deformed under load compared to a flat foam. Maximum deflection, surface area and displaced volume were calculated to lend insight into how people transmit load to a cushion.

RESULTS

The results of the pressure analysis are shown in Table 1. Both main effects, shape and stiffness, are significant. Sitting on a HR45 cushion (flat or contoured) results in a lower pressure distribution than sitting on a HR55 cushion. Also, sitting on a contoured cushion (HR45 or HR55) results in a lower pressure distribution than sitting on a flat foam of similar ILD. The contour and deflection characteristics on the HR55 foam are displayed in Table 3. The results from the HR45 tests are similar but are not included due to space limitations. Sitting on a CCC induces much less displacement than sitting on a flat foam. On the average, contouring foam will increase the surface area by 2% when compared to a flat cushion. Contouring foam also offers an increase in displaced volume with a CCC exhibiting an increase of 64% over a loaded flat cushion.

DISCUSSION

Results of the pressure comparison indicate a difference in the mean pressure depending on stiffness or shape. The HR45 foam provided seating support at lower pressure than the stiffer HR55. Generally, a softer more compliant material will wrap around the buttocks which results in better enveloping. However, some materials are too soft for a seating application, will deform too much and reach a bottomed out condition during which high interface pressures result. The main interest of this study, however, concerns the performance of contoured foam. The results indicate that sitting on a CCC results in a lower pressure distribution than sitting on a flat foam. This result is encouraging for the development of contoured foam for use in wheelchair seating. The effectiveness of contoured foam can be partially explained by analyzing load transfer from the body to the cushion.

The precontouring of foam affects the loading and deformation of the buttocks. These effects can be explained via changes in the enveloping property and available surface area of the cushion. Given a certain load on a cushion, the interface pressure will decrease with an increase in area. A flat foam cushion offers some increase in surface area as the cushion deforms under load. As shown in Table 3, a loaded CCC offers an increase of approximately 4% over a noncompliant surface and 2% above a loaded flat foam.

While this increase in surface area does not appear to be great, any increase in area over which force is transmitted is beneficial. This may also be an indication that load is being transferred through different areas of the buttocks. This is a beneficial aspect of contoured foam and is evident when analyzing the displaced volume characteristics.

Body tissues are subjected to several types of pressure. Hydrostatic pressure, normal pressure and shear pressure have dramatically different effects on soft tissue. Generally, normal and shear pressures distort tissue while hydrostatic pressure does not. A cushion that exhibits good enveloping characteristics would increase the amount of hydrostatic loading and produce a more uniform pressure distribution. The results indicate a 64% increase in displaced volume. The buttocks will be encompassed more because of this increase. The cushion will apply more side pressure which should result in increased hydrostatic loading. In addition, further deflection is reduced at the site of maximum indentation suggesting less compression at the site of greatest load transferral. In fact, less compression occurs throughout the gluteal region which results in less surface tension and decreased shear effects as the cushion and buttocks reach equilibrium. Referring to the mean pressures and standard deviations on flat and contoured HR55 foam listed in Table 2, the pressures measured on a CCC exhibit less variability and therefore represent a more uniform pressure distribution. These three important attributes- increased enveloping, decreased foam compression and a more uniform pressure distribution- are typical of a safer sitting surface and may indicate less tissue distortion.

Table 1. Pressure Comparison on Two ILDs (Stiffness) of Flat and Contoured Foam (Shape)

Group Means (mm Hg):	HR45	HR55	Flat	Contoured
	45.6	51.8	52.5	44.9

Analysis of Variance

Source	D.F.	Mean Sq	F
Subject	10	583	
Stiffness	1	10231	17.5*
Shape	1	15402	15.8*
Stiffness x Shape	1	904	3.1
Subj. x Stiff. x Shape	10	291	

* significant at p<.005

Table 2. Mean Pressures (mm Hg) & Standard Deviations on HR55 Foam

Subj	Flat HR55 Pressure	(SD)	Contoured HR55 Pressure	(SD)
A	63	(25)	42	(13)
B	47	(13)	53	(9)
C	53	(38)	51	(23)
D	86	(35)	68	(35)
E	38	(10)	39	(7)
F	72	(29)	52	(17)
G	54	(30)	54	(19)
H	46	(9)	36	(4)
I	48	(20)	34	(10)
J	65	(50)	50	(27)
K	50	(17)	39	(11)

In conclusion, contoured foam cushions, when compared to flat foam, seem to provide a seat interface that is less damaging to soft tissue. The buttock-cushion interface seems to exhibit more hydrostatic pressure and less compression and shear due to the shape of the unloaded foam. While this study advocates the use of contoured foam for wheelchair use for pressure and tissue distortion reasons, subsequent studies will investigate the effect of CCCs on functional and postural considerations. Only then can a cushion be designed which offers a safe sitting surface without affecting the user's functional abilities.

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Table 3. Contour Characteristics of Flat and Contoured Foam

Subj	Displ. Vol(cm^3) Flat	CCC	Diff(%)**	Sur Area(%)*(cm^2) Flat	CCC	Depth(mm) Flat	CCC
1	724	1022	299(41)	1682(2.0)	1695(2.6)	32	3
2	852	1388	536(63)	1689(2.2)	1724(4.4)	39	18
3	880	1377	497(56)	1696(2.7)	1732(4.8)	37	10
4	1001	1479	478(48)	1691(2.3)	1706(3.3)	34	10
5	1598	2780	1182(74)	1698(2.8)	1756(6.3)	36	17
6	710	1340	630(89)	1672(1.2)	1697(2.7)	26	9
7	505	730	225(45)	1667(0.9)	1680(1.7)	20	7
8	439	833	394(90)	1663(0.7)	1676(1.4)	17	8
9	1895	3364	1469(77)	1712(3.6)	1788(8.2)	44	17
10	1118	1686	569(51)	1697(2.7)	1737(5.1)	43	15
11	750	1256	506(67)	1681(1.7)	1707(3.3)	34	12
Avg			617(64)	(2.1)	(4.0)		

* percent increase when compared to a 16" x 16" flat surface with an area of 1652 cm^2.

** denotes percent difference of displaced volume between a loaded CCC and a loaded flat foam.

28.1

DIRECT MANIPULATION: ITS SIGNIFICANCE FOR PEOPLE WITH DISABILITIES

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ABSTRACT

As computer interfaces incorporate more aspects of Direct Manipulation, its significance for people with physical disabilities becomes a pressing concern. This paper presents groundwork for current research at the Hugh MacMillan Medical Centre, relating the nature of Direct Manipulation to some associated problems and possible solutions.

INTRODUCTION

Direct Manipulation computer interfaces such as IBM Presentation Manager and the Macintosh Finder are gradually replacing the conversational style of human-computer interaction. These interfaces tend to represent information graphically, in icons rather than words. Instead of typing commands at the keyboard, the user can indicate objects depicted on the screen and directly manipulate them with a pointing device such as a mouse.

Direct Manipulation appears to surpass earlier methods of human-computer interaction. Shneiderman (1982, p. 251) suggests that interfaces in this style are easier to learn, more efficient to use, and less vexing than their predecessors. For many people, Direct Manipulation can make computers much more accessible than before.

For other people, however, Direct Manipulation is a further impediment: it has made computers inaccessible once more. Various ingenious techniques now allow people with sensory and physical disabilities to use traditional text-based interfaces. For example, a text-based interface can read information aloud to people with visual impairments, and people with physical disabilities can use alternative keyboards to enter data. Direct Manipulation foils these alternate access methods. An interface which presents information chiefly in graphic form and requires the use of a pointing device makes few allowances for visual or physical impairment.

THE PROJECT

A two-year project at the Hugh MacMillan Medical Centre is exploring the use of Direct Manipulation interfaces by people with severe physical disabilities. In this paper, we attempt to lay groundwork for our investigations by discussing three vital questions:

(1) What is "direct" about Direct Manipulation?

(2) What does this directness mean for people with physical disabilities?

(3) How can we make Direct Manipulation accessible to everyone while still preserving its directness?

DIRECT MANIPULATION

Hutchins, Hollan, and Norman (1986: hereafter referred to as HHN) posit that the "directness" of a computer interface depends on its semantic and articulatory properties. The former properties concern the terms of the interaction; the latter govern its form.

Semantic directness

Metaphor

To perform a task with the help of a computer, the user must approach it on the computer's terms. Too often this is alien to the user's understanding of the task. People who design documents lay them out visually: they recognize a felicitous arrangement by its appearance. Many computer text formatters, however, require the user to describe the format of a page by including special statements in the text. Such a technique is semantically indirect: it differs markedly from the user's natural approach to the task.

A semantically direct interface, on the other hand, works according to a metaphor which parallels the user's concept of the task domain. Thus users can approach the computer on terms which approximate their own. Page layout programs in the Direct Manipulation style follow this principle. The computer displays the layout visually, and users can manipulate it without having to describe what they are doing. (Cf. HHN, p. 105.)

Brevity

Specifying what tasks the computer should perform can be a lengthy process. Text-based interfaces often demand long strings of commands, and even some Direct Manipulation interfaces offend by requiring too many maneuvers. For true semantic directness, the process of specifying tasks must be concise as well as intuitive. Direct Manipulation interfaces commonly speed the entry of commands by allowing the user to select them from menus instead of typing them. (Cf. HHN, pp. 103-105.)

Articulatory directness

Mimesis

Commands typed at a keyboard bear no formal relation to the tasks they designate. The structure of the word "print," for example, is entirely unlike the act of printing which it causes the computer to perform. Likewise, words used to tell the computer to transfer a file from one disk location to another do not resemble the actual movement of the file. A screen icon depicting a printer, on the other hand, is similar to the printer itself. Dragging the image of a piece of paper between pictures of folders imitates the movement of the file. Interfaces of the latter style are more articulatorily direct than the former: the signs used to specify computer tasks mimic the tasks themselves (HHN, pp. 111-113).

SIGNIFICANCE

Metaphor

The aptness of an interface metaphor depends on the tasks the interface will perform and the experience of its users. Current Direct Manipulation interfaces follow a "desktop metaphor" where folder icons represent disk storage and pieces of paper denote files. These interfaces are intended to correspond to a paper environment such as an office or design studio.

An alternate metaphor might be more appropriate for other kinds of work or for people who are most familiar with a different real world environment. Someone using a computer as a communication aid could benefit from Direct Manipulation, but the interface should probably not mimic the use of paper. People with severe physical disabilities who cannot manipulate material objects may lack the basic spatial concepts necessary to work with representational objects on a computer screen. For them, a metaphor less tied to reality might be preferable.

Brevity

A more laconic interaction style assists users with disabilities most of all, since they often have the most trouble entering lengthy sequences of commands. Selecting operations from menus is particularly convenient. It also has the added benefit of resembling existing alternate access methods, where users who cannot type or who have difficulty typing can pick characters, words, and phrases from arrays of choices.

Mimesis

The mimetic aspects of Direct Manipulation constitute its most formidable obstacle for people with physical disabilities. Although easy to learn and intuitive to use, mimetic interfaces are extremely demanding. The user must be able to manipulate a pointing device to perform the often complex and subtle actions which represent computer operations. Currently available devices are difficult even for some able-bodied people, and people who lack the requisite physical control may find them impossible to use.

POSSIBLE SOLUTIONS

Existing interfaces

It may be possible to make existing Direct Manipulation interfaces accessible to many people who cannot use them now. Alternative pointing devices, particularly those designed for people with disabilities, can make mimetic actions easier to perform. A specially shaped joystick may be less awkward than a standard mouse, for example. People who cannot use hand-operated devices may be able to operate headpointers. Various filtering techniques can transform shaky input into smooth control.

For people who are unable to manipulate any kind of analog controller, various scanning techniques can replace many pointing device functions in a typical interface. Instead of pointing to menu choices, tools, and icons, a user can scan through them and select them with switches. A macro facility can assist in operations which require multiple selections. Unfortunately, this method abandons the mimetic directness of pointing.

Making pointing devices easier to use is a straightforward but imperfect solution. It can give people partial access to current interfaces—at least those which support alternate input devices—and it is relatively simple to put into practice. Yet it leaves the user deficient with respect to the interface, whose basic design still fails to compensate for disability.

New interfaces

The mimetic features of an interface depend on its semantic character. Dragging the image of a piece of paper between folder icons is mimetic only because the interface represents file movement in terms of papers and folders. If the interface followed another metaphor, another action would denote file movement. (Cf. HHN, p. 113.)

It should be possible, therefore, to construct interfaces with mimetic structures suited to the abilities of individual users. Thus for a person who could best move a pointing device horizontally, an appropriate interface would emphasize horizontal motions and would follow a metaphor in which this restriction made sense. Different disabilities would require different designs; the most severe disabilities would present the greatest challenges.

By incorporating less physically demanding systems of mimesis, alternative metaphors could make Direct Manipulation accessible while preserving its articulatory directness. Accommodating a user's limitations in the design of an interface would exactly match the functionality of the interface to the ability of the user. The interface would demand nothing that the user could not do.

CONCLUSION

Constructing specialized interfaces to accommodate the limitations of users with physical disabilities is a fairly daunting proposition. It involves, among other things, redesigning computer systems and applications so that their user interfaces are fully interchangeable. Yet it appears to be the most satisfactory solution to the inaccessibility of Direct Manipulation. An interface which never expects the user to perform difficult or impossible actions will never impede the user, and a metaphor attuned to the user's limitations will remove the stigma of disability.

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28.2

DIRECT MANIPULATION: PROBLEMS WITH POINTING DEVICES

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ABSTRACT

Direct Manipulation computer interfaces emphasize the use of pointing devices. For people with physical disabilities, these devices may be difficult or impossible to use. This paper describes problems some users may encounter with currently available pointing devices.

INTRODUCTION

A new style of user interface is becoming increasingly common in today's computer systems. The style is known as Direct Manipulation; it pervades operating systems such as IBM's Presentation Manager™, Apple's Macintosh Finder™, and Open Look™ UNIX. Direct Manipulation interfaces fill the computer screen with *objects*, often graphic, which represent data. Users work with the underlying data by selecting objects and *directly manipulating* them with a *pointing device* such as a mouse, trackball, or touch tablet.

For many people, Direct Manipulation is a powerful and intuitive method of interaction. The pointing device governs the movement of a cursor on the screen which serves as the user's "electronic finger," a virtual extension of the body. Electronic pointing is very demanding, however; it requires the user to have considerable fine physical control.

A two-year project at the Hugh MacMillan Medical Centre seeks to make Direct Manipulation accessible to people with physical disabilities. In this paper, we summarize the three basic actions involved in electronic pointing and the characteristics of various pointing devices. There are six areas where we expect some users to have difficulty with the technique.

POINTING ACTIONS

Movement

Moving the cursor about the screen is essential to electronic pointing. Pointing devices control the cursor in various ways. *Relative* devices such as the mouse shift the cursor in proportion to some movement of the device. *Absolute* devices such as the touch tablet translate locations on a control surface directly to locations on the screen.

Selection

Simply moving the cursor over an object on the screen does not affect it. Pressing a button, usually mounted on the pointing device, *selects* the object under the cursor and picks it out for manipulation. As an alternative, some pointing devices allow the user to select an object by holding the cursor over it for a period of time.

Dragging

Unlike normal cursor movement, *dragging* the cursor affects the screen representation beneath. Dragging combines cursor movement with selection, usually requiring the user to hold down the selection button while manipulating the pointing device to move the cursor. A few pointing devices permit the user to *toggle* selection on before dragging and off afterwards, so that the button need not be held down.

POINTING DEVICES

Relative Devices

A *mouse* detects its own motion over a flat surface. Sliding the mouse shifts the screen cursor a proportional distance in the same direction. Rolling a *trackball* has the same effect, as does head movement with a *relative headpointer*. Tilting the pole of a *proportional joystick* "drives" the cursor at a constant speed corresponding to the degree of tilt. The pole is spring-loaded to centre itself and leave the cursor at rest.

A *cursor keypad* consists of keys for different directions of movement. Most computer keyboards have cursor keys which applications use for specific purposes. It is also possible to use a cursor keypad as the general pointing device for a Direct Manipulation interface. Pressing a key moves the pointing cursor one unit (one or more screen pixels) in the related direction; sometimes holding the key down moves the cursor repeatedly. A *gated joystick* works the same way: tilting its pole shifts the cursor unit by unit in the chosen direction.

Absolute Devices

The flat surface of a *touch tablet* responds to pressure. Touching a point on the tablet transfers the cursor directly to the equivalent location on the screen. A *touch screen* is similar; its sensitive surface is mounted over the computer display so that tablet locations visibly correspond to screen locations. A *lightpen* picks out points on the screen when held against it; a *long-range pointer* does so from a distance.

Each pole position of a *positional joystick* corresponds to a location on the screen. An *absolute headpointer* translates the position of the user's head to a screen location. (Note that headpointers can often be used with body parts other than the head.)

PROBLEM AREAS

Device Contact

The physical design of pointing devices may make them difficult to manipulate. A mouse must be grasped in the hand, and its cord is easy to get tangled in. Rolling a trackball with even pressure and speed is a challenge, especially if the body part used for contact is neither flat, smooth, nor evenly controllable. Grasping and releasing the pole of a joystick may be hard for some people and impossible for others, such as those who use headsticks. Some people may not be able to isolate and control a digit in order to press distinct locations on a touch tablet. Targeting individual keys on a cursor keypad is tricky, and after holding down a key for continued motion in one direction, some may not be able to release it in time.

As a further complication, the user must frequently shift the locus of activity from the pointing device to another input device such as the keyboard. Mounting selection buttons separately from the pointing device increases the problem. Yet some people may not be able to isolate digits to press buttons mounted on the pointing device itself.

DIRECT MANIPULATION: PROBLEMS

People who can use a pointing device for movement and selection may still have trouble with dragging. Dragging generally requires the user to move the pointing device while holding down a button. Some people may not be able to control two contact sites or perform two actions (pressing and moving) simultaneously—especially when each involves a different body part.

Stability

Some devices are difficult to keep under control. If a device requires considerable movement on the part of the user, and especially if the movement is unconstrained, reliable and accurate pointing may be impossible. The mouse is particularly devious: because the entire device is movable, it is easily disoriented, and it can even be jerked completely out of range. A touch tablet's wide contact surface can generate unintentional input from accidental pressure. The upright pole of a joystick is easy to bump or accidentally grasp or release. With all devices, initiating and changing directions (especially diagonal) is apt to be more awkward than continuous movement in a single direction.

Since the buttons on a mouse or a joystick are part of its movable pointing controls, many will find it difficult to press a button on one of these without shifting the device and moving the pointing cursor. Holding a device steady for timed selection is equally precarious. The user can also unintentionally displace a device if the effort of pressing its button "overflows" and causes involuntary movement. A headpointer is particularly susceptible, since overflow of effort in the body part controlling the switch is most liable to affect the head. As for dragging, keeping pointing motion under control while pressing a switch at the same time is likely to be especially challenging.

Feedback

To know the location of the pointing cursor, most pointing device users supplement their view of the screen with a proprioceptive sense of the position of the device. Inadequate kinaesthesia or unusual manipulation techniques may eliminate this physical feedback. Some devices, furthermore, such as the cursor keypad and proportional joystick, cannot physically reveal the location of the pointing cursor. Thus many people must rely on visual feedback. Unfortunately, having to concentrate on manipulating a device can distract these same people from the screen. Devices especially apt to absorb the user's attention are the touch tablet and cursor keypad with their multiple contact sites, and the unstable mouse and trackball. Selection and dragging demand further visual attention to the pointing device.

Resolution/Range

People who lack fine motor control may need their physical pointing actions to be scaled down for the fairly delicate requirements of direct manipulation. Downward scaling, however, can make covering the entire area of the screen display awkward and time-consuming, especially for users or devices whose range of movement is limited. Thus fine resolution conflicts with wide movement.

Absolute devices require the user to assume physical positions exactly analogous to screen position; actions must be similarly precise. The touch tablet is especially demanding: for each point on the screen there is but one analogue on the surface of the tablet. The joystick's narrow range of movement makes the scaling problem acute.

Headpointers have a specific scaling problem. The user's range of head movement determines the minimum distance from head to screen: the wider the former, the shorter the latter. If the former is limited, the latter may be too great for visual comfort and fine resolution.

Because relative pointing devices allow reorientation, downward scaling becomes more feasible. When a mouse has reached the border of its movement area, the user can pick it up and reposition it; the user can likewise adjust his hand over a trackball. Fine movement control is exceptionally easy using cursor keys, and control even at the pixel level is possible. Under extreme downward scaling, however, wide-range cursor movement requires considerable manipulation. Note also that a relative headpointer cannot be reoriented. Often the cursor has not reached its target when the user's head is turned as far as it will go, and at this point the user can hardly remove his head and reposition it.

Physical Loading

Use of a device may cause fatigue, pain, or injury. The mouse and trackball require a lot of movement and are therefore tiring. Covering a wide range with the latter takes a lot of separate pushes, after each of which the user must reorient. The alternative is one long push, maintaining contact between body and device throughout. Continual rubbing against the contact surface of a touch tablet may chafe. Bumping against the pole of a joystick may bruise. When using headpointers, members of the research team suffered strained vision from unrelieved attention to the screen, as well as headaches from tense neck muscles.

Mental Loading

The complex actions involved in manipulating a device may claim excessive mental effort. Whereas the pointing cursor moves in the vertical plane of the screen, all devices except for touch screens, headpointers, and lightpens move in a horizontal plane. The movement of a positional joystick is not planar at all. "Driving" the cursor with a proportional joystick is less intuitive than moving it with other devices.

CONCLUSION

The coming wave of computer systems incorporate Direct Manipulation interfaces. These depend on pointing devices which are difficult or impossible for some people to use. If computer systems in the near future are to be accessible to everyone, their interfaces must allow less demanding methods of electronic pointing. Alternative pointing devices can accommodate some users, but others may need a somewhat different style of interaction. We are investigating Direct Manipulation and its use of electronic pointing in the hope of devising an interface better suited to varying abilities.

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28.3

AN INTEGRATED VOICE-ACCESSED COMMUNICATION MODULE FOR THE PHYSICALLY HANDICAPPED

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ABSTRACT

Investigators at the University of Tennessee at Chattanooga (UTC), have developed an application of voice recognition which enables voice commands to operate a speech messaging and telephone communications system, Voice-Accessed Communication Module (VACM), designed for time efficiency, ease of use, and user-friendliness. This system can be used for many applications, including the enhancement of productivity, and the development of independent-living, for disabled persons. This report describes VACM, and shows how voice access can be used to replace keyboard access for appropriate applications.

INTRODUCTION

Computer voice recognition applications provide a powerful computer access tool for anyone who has repeatable and functional speech control(1,2,3).

The VACM system itself is a product of UTC's Advanced Computer Applications Laboratory, (ACAL). The voice access option is a result of efforts of UTC's Rehabilitation Interface Engineering (RIE) group in the human-machine interfacing area at the Center of Excellence for Computer Applications (CECA), in their efforts to develop an integrated and comprehensive environment for computer access and independent-living for the disabled(4).

METHODS

VACM is a module which runs on a RIE workstation at UTC, and as such, is a subsystem of a comprehensive computer access environment under development.

The VACM system is an integration of hardware, an integration of software, and the addition of a user-friendly front-end to accomplish the goals of ease of use, user-friendliness, and time-efficiency for the user.

Speech technologies included are voice recognition, speech synthesis, speech digitizing for recording and playback, and telephone management.

Interfacing and computer access methods used include keyboard redefinition to provide single-stroke neumonic keyboard commands, single-switch access of scanned menus for those without keyboard skills, and keyboard emulation via voice recognition.

Ease of use and training, and user friendliness are achieved through the single-stroke neumonic keyboard commands, and simple neumonic voice commands.

Finally, time-efficiency for the user and convenience or ease of use are enhanced using memory-resident software which is always ready, to provide almost instantaneous access to the telephone system, or to a voice-messaging system.

The IBM-PC, or compatible microcomputer, was selected because of its wide usage, and the large selection of peripheral devices available. Hardware integration is provided via the PC Bus, the RS232 serial ports, and the parallel printer ports, all readily availible in this series of microcomputer.

Voice recognition is provided by the "VoiceScribe-1000" speech recognition system from Dragon Systems, Inc(5).

Telephone management and digitized voice functions are performed by the "Watson" system from Natural Microsystems, Inc(6).

The implementation is coded in the "C" programming language, using MS-DOS batch file and file handling facilities to provide the software integration.

RESULTS

VACM allows you to record and store messages in your natural voice on individual note cards. Anyone with local or remote telephone access to VACM may play back these notes at any time. You can instantaneously find any note card or recorded note, edit the notes or erase the card when the notes are obsolete.

The VACM system automatically locates and selects the appropriate telephone number to use to reach an individual depending upon time of day, or day of week, and dials that number. If that number is busy, VACM redials it and notifies the caller when the call is complete. VACM can even autocall and leave important voice messages.

VACM maintains an accurate content of all notes recorded and the exact time and date of the recording.

All this is done with a few simple keystrokes on the VACM Computer Terminal. VACM recognizes voice commands to perform the same functions as the simple keystrokes. With the addition of a standard telephone or headset and a switch you can perform all these functions using your natural voice by talking to VACM.

DISCUSSION

The VACM system is ideally suited as an application of voice recognition technology. None of the functions performed are critical, life or death, or dangerous functions. Therefore, if there is an occasional mistake made, no harm is done, and the command only need be repeated by the user to perform the desired function properly.

VACM is an important and effective module in UTC ACAL group's efforts to develop an independent-living computer access environment for disabled persons4. It is currently being implemented and tested by students at the ACAL laboratory at UTC, with the aid of a local high-level quadriplegic businessman.

VACM can provide productivity enhancement in the communication, messaging and telephony requirements of disabled persons.

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28.4

INTEGRATING VOICE OUTPUT WITH STANDARD APPLICATIONS USING COMMERCIAL SOFTWARE ON THE IBM PC

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INTRODUCTION

Physically disabled people can use standard software computer to pursue educational, vocational, and personal goals in such areas as written communication, financial analysis, and engineering design. For nonvocal individuals, computer use can also provide a means of spoken communication. Using a single computer for both voice output and other computer tasks is cost-effective, space-efficient, and simple.

While it is impossible to perform more than one activity concurrently on a single computer, it is natural and sometimes necessary to communicate verbally while performing other tasks. One solution to this problem is to provide a means of switching between voice output and other computer tasks as quickly as possible. Ideally, this approach allows a user to run any standard application software, quickly switch to spoken output as desired, then return to the same place in the original task.

This paper presents a new implementation of a system on the IBM PC compatible computer, in which standard word processing software is used to provide both speech output and written communication. Techniques for rapidly switching between voice output, word processing, and other computer applications are discussed.

BACKGROUND AND REVIEW

The ability to use standard software should be combined with convenient access to speech output to provide a comprehensive system for the non-vocal user. The main criteria for such a system include:

- efficient production of spoken communication,
- transparent access to any commercial software,
- fast and non-disruptive switching between speech output and other tasks.

Current approaches to this problem can be classified into three categories. The first combines dedicated voice output communication aid hardware with the PC compatible computer. The communication aid provides a means of alternative text entry and spoken output of that text. It can be connected to the PC via a keyboard emulator to allow use of standard software on the PC. The major disadvantage of such a system is that both a communication aid and a computer are required, which can be expensive and bulky.

The second approach uses a single piece of dedicated software for spoken communication, written communication, and/or other functions. Integrating several user tasks into one package can make it efficient to switch between activities. However, the performance of each individual function cannot match the power of the "equivalent" commercial software, and many tasks, such as business analysis or high-quality graphics, are simply not available in such dedicated packages. Another drawback to this approach is that the alternative access method is bundled with the dedicated software, so use of other software requires a second means of alternative access, which can add expense and complexity.

A third category is comprised of memory-resident programs that combine alternative access and speech output. Ideally, this provides transparent access to all commercial software and makes speech output available from within any program without disrupting the current task. In practice, memory-resident programs display incompatibilities with some applications. In addition, the small number of available systems in this category limits the choice for an the alternative access interface.

METHODS

We have developed a new approach that eliminates the need for specialized speech output software. The primary use of this system is as the basis of an integrated workstation for spoken and written communication. Standard word processing software is used for speech output, which provides a natural integration of written and spoken communication. This method stems from the capability of most word processors to direct print output to any I/O port using a choice of printer drivers. To generate speech on a serial speech synthesizer, the message can be "printed" to a serial port, using an ASCII printer driver.

Text entered by the user can be spoken directly from the word processing program by executing a "print" command. Choice of an alternative access method for text entry is then unrestricted; it need not support speech output on its own. Text entry can be accomplished by whatever means is most efficient for the user, from standard keyboard access to single switch scanning, and may incorporate any appropriate rate enhancement technique.

With many commercial word processors, more than one window of text can be displayed on the screen simultaneously. With two windows on the screen, one window can be used mainly for written text (e.g., business correspondence, personal writing), and the other can be used for the development of communication for vocalization. Text in either window can be directed to the printer or speech synthesizer. Typically, when in the writing window, text will be sent to the hardcopy printer; when in the speech window, text will be directed to the speech synthesizer. This allows the user to leave the writing task temporarily, have a conversation, and return, without affecting the contents of the written text.

Standard features of many word processors supply additional capabilities to the system. For example, the ability to load new files allows the user to develop pre-stored communication files for common topics and switch between them as desired. A macro expansion feature provides a means of abbreviation expansion when writing or speaking. In addition, long command sequences, such as those required to redirect output to a new port, can be attached to a single selection for maximum efficiency. Finally, a feature that provides "printing" (speaking) of a single line of text eliminates the need for the user to explicitly select the text to be spoken in many cases.

Many users need to run other application programs in addition to a word processor. Exiting the word processor for this purpose is undesirable, since speech output becomes impossible while the other application is being used. The ideal situation to rapidly switch between the speech output window and other application programs using one or two selections, without the overhead of exiting one program and running another one. This is possible using an extended DOS environment such as DESQView[a]. These environments provide fast switching between applications. When the user leaves one application to go to another, the state of the program is saved, so the user returns to his/her original place.

CASE STUDY

M.E. is a 45 year old woman with a progressive movement disorder of unknown etiology. She is severely dysarthric and has the ability to use a standard keyboard with one finger. She is very intelligent and has a great interest in writing, with a goal of publishing a collection of her poems. A portable system that combines high quality output of both written and spoken communication is required. She uses Microsoft Word[b] running on a laptop computer as her means of both spoken and written communication. Text output can be directed to a portable speech synthesizer or a printer as desired. To enhance her keyboard use, she uses the 1-finger[c] program for chording keystrokes and the Quickey[c] program for abbreviation expansion. In the future, she will also be using a drawing program for clothing design. The DESQView environment will be added to her system at that time to allow fast switching between graphical design and voice output tasks.

DISCUSSION

The system presented meets the three criteria listed above for a multi-purpose workstation used by nonvocal individuals. First, the efficiency of spoken communication is primarily determined by the alternative access method used. The system can be used with any available access system for the IBM PC compatible, not only those that incorporate voice output. Choosing from this wide range of options improves the likelihood of maximizing the text entry rate.

Another factor affecting communication efficiency is the overhead associated with selecting the text to be spoken and executing a "print" command to send the text to the speech synthesizer. This factor must be carefully considered before using a word processing package for voice output. Word processor features such as single line printing and macro creation, as mentioned above, can minimize this overhead.

The system also meets the second criterion for transparent access to applications. The degree of compatibility with other application software depends on the alternative access system used. Transparent access to commercial software can therefore be achieved by using an alternative access system with a high degree of compatibility.

Finally, the criterion for fast task switching is addressed, since the system gives the user quick access to spoken communication at any time. When two word processing windows are used to separate written and spoken text, switching between speaking and writing requires only a single selection. Similarly, switching between applications with an environment such as DESQView can be done with one or two selections. One limitation in using concurrent environments is that all applications being used must fit simultaneously in the computer's RAM. Standard capacity of 640K is often enough for two large applications (e.g., word processor and spreadsheet). However, if other applications are loaded, or if the alternative access method requires too much RAM, additional memory may be required.

CONCLUSION

A system that uses commercial word processing software to integrate voice output with other tasks has been presented. This system separates the voice output function from the alternative access method, unlike other approaches that bundle those two features. This approach allows the use of any desired alternative access system. This provides the clinician with a greater degree of flexibility in configuring the system, which can have a major impact on the communication rate attainable with the system as well as its compatibility with other applications.

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28.5 Evaluation of Text Processing Using a V-KIM Window

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Abstract

V-KIM was designed to interface the severely neuromotor disabled to an IBM-PC. V-KIM was packaged with a variety of windows including the RPM with its 30,000 word dictionary to provide the user with some tools for producing text. Testing was performed to determine the speed in which text could be produced with this package. This paper reports the testing procedure and results.

Introduction

V-KIM(1,2) is a memory resident program designed to allow menu selections made with a four switch input device to replace standard keyed input for commercial software programs such as WordPerfect and Multimate. It operates on an IBM-PC under MS DOS. RPM(3) is a method for retrieving words from a dictionary with minimal input. RPM and several other menu designs were combined with V-KIM and tested with 12 clients for its effectiveness in word processing for adults with neuromotor disabilities.

Methodology

Responses to a questionnaire directed to the disabled students at Wright State U. led us to 12 clients who were interested enough to devote some time to testing. Initial interviews indicated that the clients had little or no previous computer experience, so training began with familiarization with the equipment.

In the early sessions, clients tried various assistive devices and were matched to an input device for use with V-KIM. V-KIM requires 4 switches, which are either the 4 arrow keys on the normal keyboard, or 4 switches wired into these keys. A variety of joysticks, each with its own feel, plus several sets of buttons were available for use. The device could quickly be changed, as mini-jacks were wired to the arrow keys and the devices plugged into the jacks. Most preferred one of the joysticks since it allowed them to concentrate on the screen as they did not need to look away in order to find the correct switch to press. Spastic motions, though, would sometimes be interpreted as input, so we used buttons with some clients in order to overcome this problem. The input device was clamped or set on a tray that was adjusted to a comfortable height and distance from the computer screen.

Clients were then familiarized with PC-Write, the word processing program being used with V-KIM, and each window presented through V-KIM. Each client was given a typing test to ascertain his ability to produce text without any specialized software. A pretest using V-KIM was then given to establish a baseline. This was followed by 3 hours of training, a midtest, 3 additional hours of training, post-test 1 with the same text as the two earlier tests, and post-test 2 with new text to copy. The results of the tests for each client can be seen in Figure 1.

The V-KIM interface could be active or inactive. When active, requests from the applications program for keyed input would be directed to V-KIM which would display a window on the screen. A main window allowed immediate access to RPM, or windows to access the 40 most common words, for building text symbol by symbol, or to a chain of custom designed windows of commands and character strings, such as frequently used words or phrases. Features incorporated in the windows provided for capitalization of words and automatic addition of the space between words. See Figure 2 for samples of the windows.

During the training sessions, clients were video taped for later observation by the project directors. The clients were asked to verbalize their thoughts, questions, and frustrations during training sessions. Sessions were normally one hour long. The trainer often paired clients for sessions prior to the mid-test. Practice sessions normally involved the client copying printed text, such as that in Figure 3. The reading level of the material was considered so that no client would be overwhelmed with its difficulty, yet the material was to have a variety of word sizes to encourage using each type of window. Users were encouraged to take longer words from the dictionary, common words from that menu , and build other words. Most of the clients shied away from the dictionary, partly because mistakes could not be as easily corrected in RPM as in the other windows.

Of the 12 participants, 6 had cerebral palsy and were quadriplegic. Two were spina bifida with arrested hydrocephaly. There was one each of arthrogryposis manifesting stiff, rigid joints, juvenile arthritis, spinal cord injury quadriplegic, and learning disabilities (dyslexia).

Results

The tests performed produced accurately spelled words from 1 to 3.7 words per minute. The best rate was by the most disabled client. This suggests that the system would be most advantageous to the severely handicapped. Those that can interface to the computer through expanded keyboard, keyguards, and similar adaptive devices should in most instances remain with them. It is important to note that V-KIM itself does not place the restriction on speed, but the windows being packaged with V-KIM play a much greater role in limiting the output.

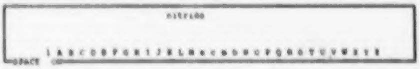
The literature has numerous examples of augmentative keyboard layouts reported to improve text production by reducing key strokes. However there are no hard engineering data which provide a designer with definitive guidelines. This has led us to current research for identifying optimal menus using throughput as a criteria instead of words per minute. A number of different window designs are being investigated.

CLIENT	TYPING	PRE	MID	POST1	POST2
1	4	1.65	3.25	3.2	3.65
2	11	1.85	2.35	N	N
3	14	2.1	3.9	4	3.5
4	15	2	2	3	2.9
5	17	1.65	3.25	4.3	3.6
6	5	0.7	0.9	0.85	1.05
7	16	2	2	2	1.9
8	24	2.05	3.45	3.6	2.8
9	24	2.25	3.7	4	2.75
10	6	.5	.95	1.05	.95
11	5	.5	.2	.75	1.4
12	18	1.5	1.35	1.85	1.85

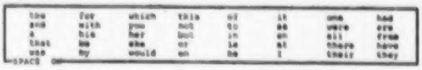
N-not available

Figure 1. Test Results

A. RPM Window



B. Common Words



C. Word Building

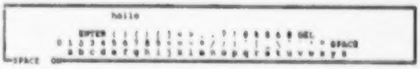


Figure 2. Sample Windows

"Information is made up of words, numbers, and symbols that convey knowledge which can be used in many ways. The mass of information we have is expanding at a rapid rate. It has caused a paperwork explosion. One of the major results is a revolution in the way information is processed in the office. The most widely used term for such work is word processing. It is a system that involves workers who are educated to use specific procedures and electronic equipment."

Figure 3. Sample Text

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Acknowledgement

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28.6 CLINICAL EVALUATION OF A PROTOTYPE PORTABLE ELECTRONIC MEMORY AID

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ABSTRACT

A study of the use of portable electronic devices as memory aids for persons who have sustained closed head injuries is underway at The Rehabilitation Institute of Pittsburgh. We are focusing our research on patients with cognitive problems who experience difficulty following their daily schedules. Prototype test units, capable of providing an individual with both spoken and printed messages at pre-set times throughout the day have been developed as part of this project and are currently being tested in clinical settings. Another paper, by the same authors, in this Proceedings outlines the motivation for our study and details our hardware implementation.

INTRODUCTION

Our research focus is on the evaluation of an interactive memory aid for head injured patients in the middle and late stages of recovery as characterized by levels V-VIII of the Rancho Los Amigos Scale of Cognitive Functioning. These patients are often disoriented to some degree and suffer from varying degrees of memory impairments (1). For example, individuals in the middle stages of recovery may be able to carry out structured activities in therapy sessions or need little assistance with activities of daily living, but initiation to perform a prescheduled task or awareness that they should be at a particular place at a certain time is lacking. Although in the later stages of recovery most patients exhibit less confusion and are generally more oriented, many still have great difficulty in maintaining attention and in learning and monitoring their daily schedule (2). Given the continued difficulty that many head injured patients have with follow through of their daily schedule, we chose to concentrate on evaluating the effectiveness that an electronic memory aid would have on this skill.

HARDWARE

Portable, programmable test devices are capable of providing pre-timed prompts in both a visual and spoken format. Messages are constructed from a stored vocabulary and can be customized to meet the needs of each patient. The test devices also serve as data collection units by recording the time delay between the presentation of a prompt and the arrival of a target destination.

An indepth description of the prototype test units can be found in another paper in this Proceedings.

METHODOLOGY

Subjects are current inpatients of our facility who carry a diagnosis of traumatic brain injury or closed head injury. The ages of our subjects range from late adolescence through early adulthood.

The level of cognitive functioning of our subjects ranges from level V through level VIII on the Rancho Los Amigos Scale. Subjects will exhibit difficulty following a daily schedule independently, but, will be able to carry out structured tasks in therapy sessions. Subjects must demonstrate adequate performance on (a) a spatial orientation task to verify their knowledge of specific places within the facility and (b) a vocabulary comprehension test to ensure their understanding of the vocabulary selected to generate device messages. Both these tests were developed as part of the research project. If a subject exhibits overly aggressive behavior or makes attempts to leave the building, they are excluded from this study.

An Alternating Treatment Design for evaluating several interventions within a single subject was selected to control for maturational and recovery factors. Using this design, the memory aid and the log book (with schedule) are defined as the treatment inverventions. Initially, five days of baseline data will be collected with a patient using a log book. Immediately following the baseline period, the log book will be alternated daily with the memory aid. This will continue until the data shows a clear and consistent change in the time delays tracked daily. The results will be graphed and interpreted. The data collected on days when the log book is in use is the time lapse between when the patient checks the schedule to identify the next therapy or is told what the next therapy is, and the time they arrive at that treatment area. On days when the memory aid is in use, the data collected is the time delay between when a prompt was issued by the device and the time the patient reaches the appropriate location. We felt that it was important to also collect observational data about the patient's responsiveness and the events which occur during this type of transition. Staff have been instructed to monitor the patient's behavior in an unobtrusive way.

Additional information will be gathered from each patient about the operational characteristics and features of the memory aid.

This feedback will be used to modify the design for future versions of a portable electronic memory aid.

RESULTS

This paper describes a research study in progress. Data and results that are completed by June, 1989 will be reported at this conference.

CONCLUSION

Evaluation of a prototype electronic memory aid for persons who have sustained closed head injuries with resulting memory and executive problems, has been underway at The Rehabilitation Institute of Pittsburgh. The focus of the study is to assess the effectiveness of such a device on a patient's ability to independently follow their daily schedule.

If we measure functional improvements in patients with head injuries, there are three roles that the interactive electronic memory aid could mediate: (a) this type of memory aid will be useful as a long-term assistive device to compensate for memory and self-monitoring problems, (b) this type of memory aid will be used as a temporary therapeutic tool to speed recovery and allow for more effective utilization of clinical time to develop compensatory strategies, or (c) the patients were more motivated to perform more independently because attention was being paid to the target task. Our clinical research seeks to differentiate between these possible outcomes.

ACKNOWLEDGMENTS

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31.1 SKIN CAPILLARY BLOOD FLOW UNDER VERY LIGHT PRESSURE

I: Development of Skin Indentation Apparatus

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ABSTRACT

Preliminary studies showed that the laser doppler flowmeter does not accurately measure skin blood flow under conditions of high loadings, since instrument errors become increasingly significant as blood flow is reduced by loading [1]. Therefore, a new apparatus has been designed to apply only small displacements of the skin while making accurate simultaneous measurements of skin displacement and skin blood flow.

Loads of 2 to 120 grams (corresponding to pressures of 0 to 40 mm Hg) have been applied via a 32 mm diameter hemispherical indentor, resulting in about 6 mm compression of the tissue overlying the femoral trochanter. In tests on normal subjects, measured relative blood flow has been valid only above 30 grams load, due to imperfect contact of the probe with the skin, and has been directly rather than inversely correlated with pressure in the 30-100 gram range.

INTRODUCTION

Within the spinal cord injured (SCI) population, some patients are significantly more prone to develop pressure sores than others, and the reasons for these differences are not known. Since pressure sores are always preceded by a compromise of blood flow in the skin, we are investigating skin blood flow response to external pressure loading. Blood flow is occluded at about 100 mm Hg in able-bodied young subjects, and evidently at much lower pressures in older or paralyzed subjects [2].

If there are indeed differences in skin blood flow response to loading which can be easily measured, then it may be possible to identify those patients who are more susceptible to pressure sores upon admission to the hospital. This would permit focussing nursing care so as to diminish the incidence of pressure sores, with potential cost savings of $15,000 per patient per year.

BACKGROUND

There have been a limited number of studies in which skin blood flow under external loading has been measured by a number of different techniques, most using rather indirect methods [3,4]. The large variability of the curves of skin blood flow vs. pressure makes it difficult to draw any meaningful conclusions. The present study differs from previous studies in two major respects: First, a dimensional analysis is carried out to insure that all of the necessary quantities are measured and are treated in the appropriate nondimensional forms to give meaningful results; and second, the noninvasive Doppler technique is used for the direct measurement of skin blood flow [5].

A correlation between decreased blood flow and skin loading in pressure sore-susceptible persons is proposed based on evidence that connective tissue undergoes systemic and local degratation following spinal cord injury. Rodriguez and Claus-Walker [6] analyzed skin biopsies from 10 normal controls and from both sensitive and insensitive areas of 7 SCI subjects, all having pressure sores. In insensitive regions, content of four amino acids found in collagen is about half that in sensitive skin, and one-third of SCI subjects had lower amino acid contents in both regions.

METHODS

We use cylindrical or spherical indentors combined with a laser Doppler flow meter (LD 5000, MedPacific, Seattle) to measure skin blood flow response to loading in able-bodied subjects and in SCI patients who do and do not have chronic pressure sores. Dimensional analysis has shown that percentage reduction of blood flow depends upon only two dimensionless variables: (1) the ratio of skin indentation to bone depth, and (2) the ratio of indentor size to bone diameter. Measurement of pressure is not necessary, and the required measurements can be made over any bony prominence (usually the femur distal to the greater trochanter).

Skin indentation relative to the surrounding surface is measured by means of four photodetectors on the indentor support (Figure 1). Bone depth is measured by Doppler ultrasonography (Toshiba Sonolayer SAL-30A with phased array probe). The indented area is made visible by displacement of an ink-filled polyurethane film bag or capsule between the skin and indentor. Indented area is determined photographically through the transparent indentor; the photographic print is manually digitized and the mean best-fit circular area calculated.

Data were taken using an IBM-PC compatible computer with analog-to-digital conversion capability, and then transferred to the Macintosh for analysis and plotting using StatWorks (Cricket Software, Philadelphia PA). Measurements are combined to produce dimensionless plots of percent blood flow reduction vs. percent tissue compression. SCI subjects are invited to participate in a follow-up program for three months.

RESULTS

Early trials used loads of 0 to 100 gram (20 gm intervals) on four subjects' forearms with the ink retainer in place. The flowmeter chart shows clear differences between 40 gm increments (Figure 2), mainly in reduced height of pulse peaks, not in the baseline. There is a spike artifact as load is increased, presumably due to downward movement of the indentor. At zero load flow is indeterminate; the indentor bounces and still has ink under the laser probe. All these tests were short, only 10-15 sec per load increment.

The optical indentation distance sensors were tested and found to be accurate and repeatable to within 0.1 mm over a 12 mm range; nonlinearity was compensated for using a look-up table in computer memory for each sensor

(Figure 3). The pressure at the center of the indentor was measured independently and the proportionality constant relative to the applied load divided by the indentor contact area was determined (the latter measure of pressure will be used in patient trials). Nondimensional indentation (skin depression divided by bone depth) has been calculated for one subject (Figure 4).

The best-fit flow (F) vs. load (L) curve for one subject is:

$$F = 1388 + 31\ L - .33\ L^2 \qquad \text{with } r = .91$$

The "load squared" term is significant: at less than 30 grams flow appears to increase, mainly due to reduced scatter and better contact with skin; above 30 grams, flow decreases rapidly with force. This test only reached 60 grams force due to bottoming out of the balance. Other subjects have stiffer tissue overlying bone, yielding less indentation depth for equal loads (Figure 4).

The standard deviation decreases with load, reflecting less scatter and also reduced height of pulse peaks (except between 30-40 sec of the 57 gram test, which included about 10 points much lower than the minima of the remainder of the 57 gm test, when the subject jostled the apparatus). The standard deviation is only weakly dependent on which 10-second interval is measured, with the least variance at 30-40 sec.

CONCLUSIONS

Tests on normal subjects have shown that indentation depth and area can be accurately measured; blood flow is measureable above 30 grams force. Blood flow appears to be only weakly dependent on pressure in the range of 30 to 100 grams in some normal subjects and more influenced by increasing pressure in others. The laser Doppler instrument seems to be inconsistent in its ability to sense pulsatile flow. In future experiments we will test SCI patients, but as yet we can draw no conclusions about the relationship of flow to pressure in this population.

ACKNOWLEDGEMENTS We thank R. Miller, G. Scott, and J. Hill. Supported by a VA RR&D pilot grant to A. Sacks, m/s 153, Palo Alto VAMC, 3801 Miranda Ave., Palo Alto CA 94304.

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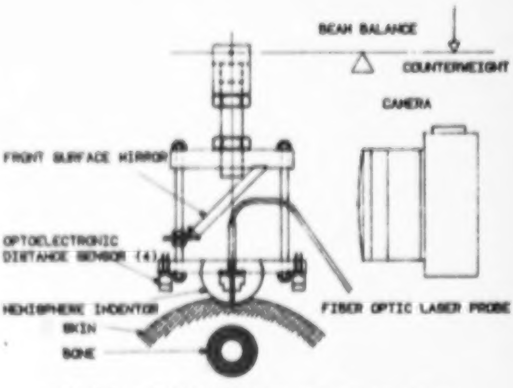

FIGURE 1: SKIN INDENTATION APPARATUS

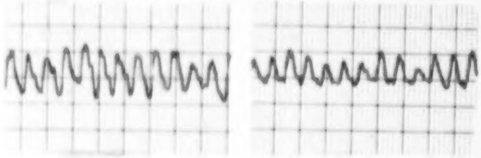

FIGURE 2: LASER DOPPLER OUTPUT
A: 40 GM B: 100 GM LOAD

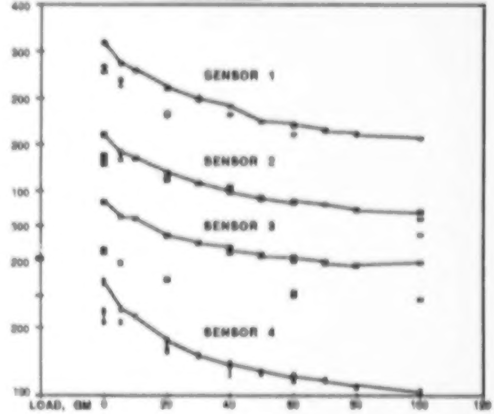

FIGURE 3: SKIN INDENTATION DEPTH, 0.001 INCH

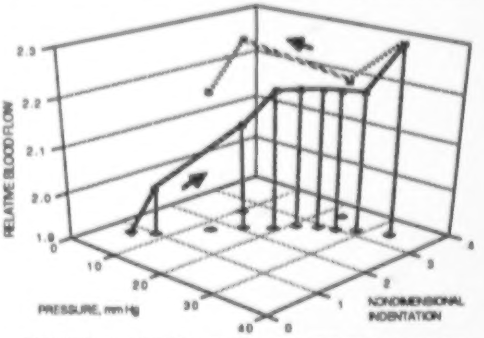

FIGURE 4: PRESSURE-FLOW-DEPTH RELATION

31.2

SYNCHRONIZED ELECTROMYOGRAPHIC, SOUND AND 3D VIDEO ANALYSIS OF PIANO PERFORMANCE, WITH COMPARISON OF THREE METHODS OF PLAYING.

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This is a pilot study aiming to measure quantitative parameters defining the different patterns of muscle and joint strain related to different methods of piano playing. One professional pianist was asked to perform three pianistic tasks from a specially selected piece, using 3 piano methods. Surface EMG data were collected synchronously with the sound and 3D video data, analyzed using the Ariel Performance Analysis software. Sound was reproducible within tasks and between methods. Deltoid activity was found to be subject-related, whereas flexor carpi radialis activity was found method-related, as well as middle finger DIP and MCP joint motion and wrist motion.

INTRODUCTION

Musculoskeletal disorders have been reported as the most common occupation related disorders in musicians. i.e. pianists. It is generally acknowledged that pianists implement many methods of playing in the course of performing to accomodate the demands of a piece in part or in whole. Each of these methods is known to cause a different pattern of muscle and joint strain. Assessment of these patterns has been largely subjective in the musical literature.

EXPERIMENTAL DESIGN

Three basic piano methods were delineated as follows for a professional pianist to perform with his right hand alone: Method A, flat hand and extended fingers; Method B, arched hand with rounded fingers and slightly flexed wrist; and Method C, quasi-right angle flexion at the knuckles. Three tasks of 5 seconds each were selected from Bach's Prelude VI in Dm (Well-Tempered Clavier), because it featured only one overall technical problem: arpeggiated chords for the right hand. Nonetheless, each task has the following distinctive properties: Task 1, jump of 1 1/5 octaves; task 2, repetitive pattern of the thumb and index finger; task 3, held notes at start and end.

Eight sets of surface electrodes, mounted on miniature preamplifiers, were placed on the following muscle groups of the right upper extremity: anterior deltoid, posterior deltoid, triceps brachii, biceps brachii, flexor carpi radialis, extensor digitorum communis, extensor carpi radialis, and flexor carpi ulnaris. Electrodes were connected to a common power supply unit and then to an analog-to-digital board.

A microphone was placed on the piano keyboard and connected to a Fairlight Voicetracker with a MIDI interface. Filters were adjusted to accomodate the musical tasks. The DC output of the instrument was connected to the A/D board in parallel with the EMG channels. A few EMG and sound samples were taken to determine the respective channels offsets and correct them digitally.

Dark markers were also placed on selected landmarks of the subject's right hand: distal interphalangeal (DIP), proximal interphalangeal (PIP) and metacarpophalangeal (MCP) joints of the middle finger, fifth MCP, ulnar styloid and olecranon. Two camcorders were placed, one from the front and one from the right side of the subject, at an angle of 75 degrees. Both cameras were initially calibrated by videotaping the same fixed geometry cube, adapted to the space to be described by the pianist's overall motion, then synchronized by an LED light (rate = 30Hz) triggered by the key that starts sampling.

The pianist was asked to use each of the 3 methods to perform each of the 3 tasks 4 times, in random order. A 3 second simultaneous video, sound and EMG sample was taken from each test, at a rate of 1000Hz for EMG and sound channels, and 30Hz for the video.

DATA ANALYSIS

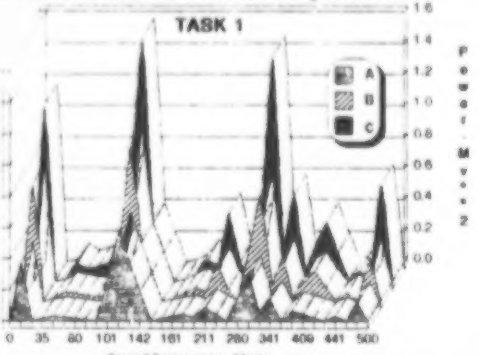
All data collected were processed with the Ariel Performance Analysis System software. First, FFT power spectra were obtained for all sound channels to check for reproducibility. Only those tests with the best matching sound frequency spectrum were selected for further analysis (Figure 1). Partial integration was performed for each of the channels at 0.5 second intervals. Data from each EMG channel were then normalized with the corresponding sound integral values and plotted (Figure 2). Video data were digitized and 3D kinematic data obtained. Ranges of motion of the various joints, in one or more planes were graphically determined and plotted (Figure 3).

RESULTS

a- As seen in figure 1, there was very little variability in the sound between the three methods, thus demonstrating good reproducibility.

b- Most muscles did not show conclusive trends in this pilot, except for the flexor carpi radialis that demonstrated significantly less activity in method A for all three tasks (Figure 2a). Deltoid activity was prominent in method A during task 1, method C during task 2, and method B during task 3 (Figure 2b).

Figure 1: 3D area-graph of the power spectrum of the sound for methods A, B and C, during music task 1.



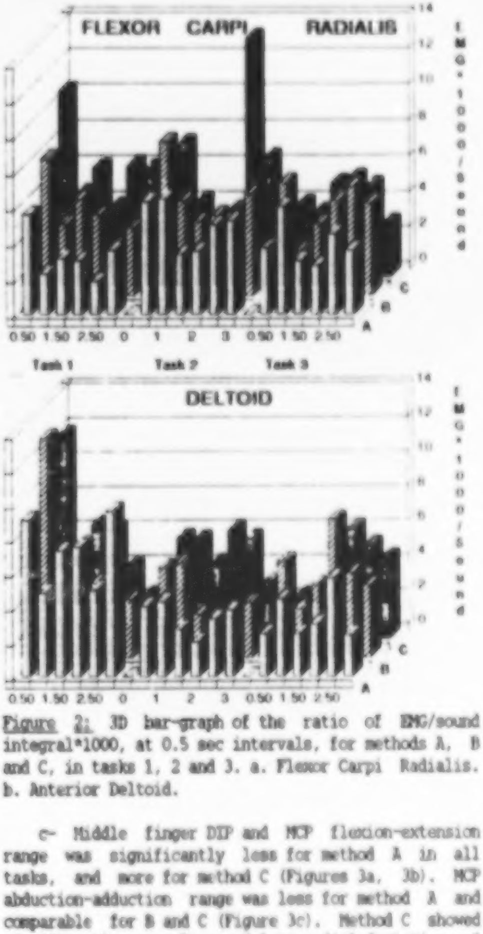


Figure 2: 3D bar-graph of the ratio of EMG/sound integral*1000, at 0.5 sec intervals, for methods A, B and C, in tasks 1, 2 and 3. a. Flexor Carpi Radialis. b. Anterior Deltoid.

c- Middle finger DIP and MCP flexion-extension range was significantly less for method A in all tasks, and more for method C (Figures 3a, 3b). MCP abduction-adduction range was less for method A and comparable for B and C (Figure 3c). Method C showed significantly more ulnar and less radial deviation of the wrist than A and B in all tasks (Figure 3d).

DISCUSSION AND CONCLUSIONS

The demonstrated reproducibility of the sound validates the experimental design used in this study. The daltoid seems to be independent of task and method in piano playing, and primarily subject-dependent; while the flexor carpi radialis seems markedly less active in method A. The latter method requires little DIP and PIP motion; while method C requires significant ulnar deviation.

This study was a pilot, all findings being merely trends and not statistically proven. Nonetheless, the experimental design was shown to be valid and will be used in further research on more subjects, specifically correlating the findings to pianists' ailments.

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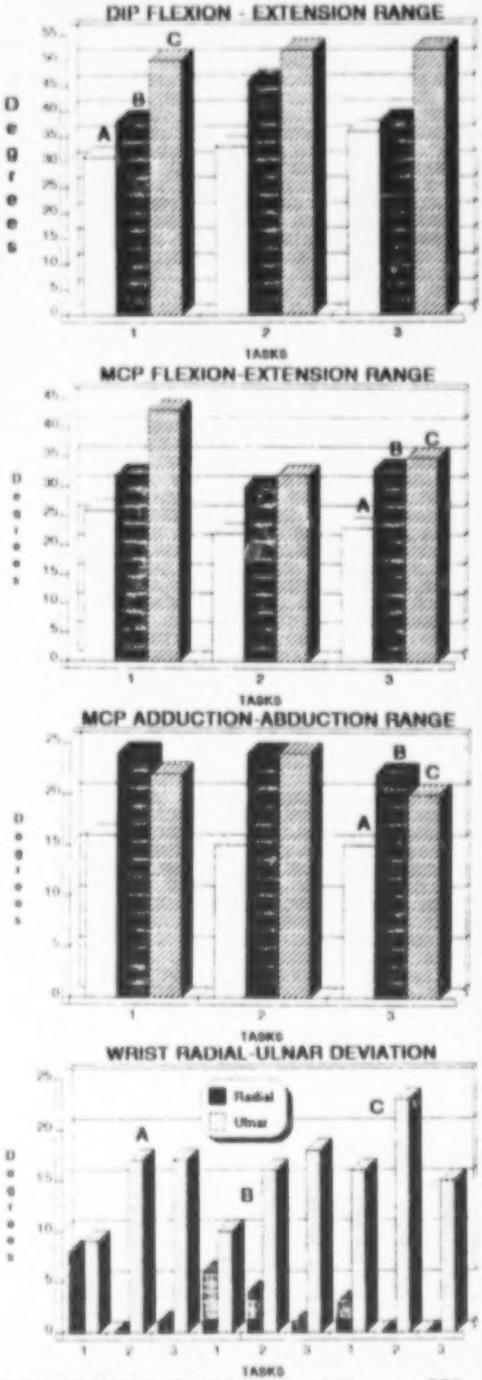
Figure 3: Bar-graph plotting joint range of motion in methods A, B and C, during tasks 1, 2 and 3. a. DIP flexion-extension. b. MCP flexion-extension. c. MCP adduction-abduction. d. Wrist radial-ulnar deviation.



31.3

THE USE OF THE COMPUTERIZED DRIVER ASSESSMENT MODULE (CDAM) FOR THE ASSESSMENT OF THE BRAIN-INJURED INDIVIDUAL

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ABSTRACT

A Computerized Driver Assessment Module developed at G.F. Strong Rehabilitation Centre and the University of British Columbia was used to assess the driving potential of brain-damaged individuals and the results were compared with a control group. It was found that the brain-damaged group had difficulty with the following: dealing with multiple step instructions, visual scanning, attending to multiple stimuli, fatigue and impulsivity. Most of these tasks require a high level of cognitive and perceptual functioning. CDAM was found to be useful in evaluating existing deficits which could interfere with driving performance.

INTRODUCTION

Brain damage often results in physical, cognitive, perceptual and behavioral impairements (Bardach, 1971). Deficiencies in any or all of these areas may contribute to poor driving performance (Bardach, 1971; Sivak et al, 1981). A literature review revealed there is no one accepted method of testing the driving potential of the brain-injured individual.

BACKGROUND

Many medical institutes restrict their driving assessments to measurement of physical factors such as range of motion, strength, reaction time and mobility (Koppa et al, 1978; Jones et al.1983). Other centres use occupational therapy or neuropsychological tests to assess perceptual and cognitive abilities related to driving (Jones et al, 1983; Quigley and Delisa, 1983). Some programs indicate they use driving simulators to assess driving performance. A major advantage of the use of simulators over on-the-road examination for the testing of disabled drivers is that quantifiable data may be obtained in a safe environment.

Drescription of the CDAM

The Computerized Driving Assessment Module (CDAM) was developed in 1985 by the G.F. Strong Rehabilitation Centre Clinical Researh Department and the Department of Electrical Engineering, University of British Columbia to meet the need for an objective method of testing the driving potential of the disabled.
The CDAM consists of the cockpit of a car with all the necessary driving controls. A stimulus arc surrounds the subject consisting of two arrays of lights: The upper yellow array is controlled by the examiner and/or the computer, and the lower red array is controlled by the steering wheel. There is an instruction monitor in front of the client. Also attached is a computer with a printer to compile and graph the results.

METHOD

Subjects were selected to provide two groups of persons: (A) an experimental group (B) a normal group who had no significant physical disabilities or history of brain damage. Subjects for the experimental group were brain injured individuals who were undergoing treatment at G.F. Strong Rehabilitation Centre. The subjects had sustained closed head injuries between 1982 and 1987. All subjects were ambulatory and subjectively deemed suitable for testing. All brain-injured patients at G.F. Strong Rehabilitation Centre are routinely referred for CDAM assessment. The subjects for the control group were recruited from the health care staff at the G.F. Strong Rehabilitaion Centre (see Table 1).

The testing was conducted individually in an assessment room free from distractions. Subjects were provided with printed instructions from the command monitor. All subjects were assessed by the same assessor who had several years experience assessing disabled drivers. Each test took approximately 1 1/2 hours.

The CDAM assessment involves the following tasks:

Section 1 Physical Ability-to manage controls (max. score 6)
Section 2 Start Procedure - start car, select drive gear
(max. score 3)
Section 3 Practice Procedure - controls and tracking
Section 4 Braking Test (brake reaction time)
Section 5 Tracking Test - A) errors avoided (max. 13)
B) mean tracking speed
C) mean reaction time
Section 6 Speed - maintain 50 kph
Section 7 Stop Procedure - park gear, engage hand brake and
shut car off (max. score 4)

At the conclusion of the CDAM assessment the results were analyzed and printed by the computer. The assessor then made conclusions and recommendations based on the objective data. These results were reviewed with the physician and a final decision as to eligibilty to take the provincial Road Test and the type of adaptive equipement necessary was made .

RESULTS

The control group statistics for the CDAM are presented in Table 2. The brain-injured subjects' scores (see Table 3) were then individually compared to these and a percentage of group failure was established. Significant is defined as greater than 30% failure for each section.

DISCUSSION

1) Do people with closed head-injuries perform significantly worse on the CDAM than a control group?

The subjects with brain damage as a group performed significantly worse than abled bodied subjects on the CDAM. The only section of the CDAM in which the experimental group had 0% errors was in Section 1 Physical Ability. This result agrees with previous studies which attribute poor driving performance of the brain-damaged individual to cognitive and perceptual difficulties rather than physical ability (Sivak et al, 1981). The only other section in which less than 30% of the brain-damaged group experienced little difficulty was Section 2A. This is a simple 1-step task which may be less cognitively demanding than the other Sections. Also as it is early in the assessment the variable of fatigue is not significant.

2) Does the CDAM indicate a specific pattern of deficits for the brain damaged group?

The subjects with brain-damage, as a group, had vaying degrees of difficulty with different sections of the CDAM. Task analysis of these sections indicates certain potential patterns of deficits related to the requirements of each. Sections 2A, 2B and 7 require the subject to follow a certain number of instructions; 1 step, 2 step and 4 step respectively. The results indicate an increasing level of difficulty for the brain-injured group as the number of instructions increases. This pattern illustrates the problems a brain-damaged person may encounter when dealing with multiple-step instructions. It may also indicate the effect of fatigue on the performance as the assessment progresses.

Section 5B of the CDAM assesses visual scanning. 61 % of the brain-damaged group had difficulty with this task. Previous studies have found visual scanning to be a problem for brain injured individuals.

Section 6 of the CDAM assesses attending to multiple stimuli. Fifty percent of the brain-damaged group had difficulty with this section.

Section 5C assesses steering wheel reaction times which 33% of the subject group had difficulty with. This may indicate psychomotor impairment. The reaction times were not slower than the control group, but faster with resulting poor performance. This indicates impulsivity as a behaviour problem for the brain-injured individual. This has also been acknowledged by VanZomeren et al (1988).

Section 4 assesses brake reaction time. Subjects tested before 1986 were not assessed on this section as it was added to the CDAM after this date. Of the experimental group 12 were assessed for brake reaction time 17% had difficulty. It is difficult to draw conclusions from this as it is a small number of subjects.

The CDAM results are consistent with previous studies which indicate cognitive and perceptual deficits of the brain-injured to be related to poor driving performance (Sivak et al, 1981) have shown that rehabilitation techniques which focus on improving these deficits and providing alternative compensatory strategies are effective for improving driving performance. The CDAM can thus be a useful tool for evaluating existing deficits which interfere with driving performance so that treatment can be planned accordingly.

3) Is the CDAM a valid indicator of on-the-road driving performance?

Conclusions are limited as generally any brain-injured subject who does not pass the CDAM would not go on to take the Provincial On-The-Road Driving Examination because of safety considerations. However there have been a few subjects who have insisted on attempting licensing, even though they failed the CDAM test. These subjects all failed the On-The-Road Exam. We can state that all subjects who passed the CDAM and went on to take the On-The-Road Exam passed it. Although the numbers are small this does support the validity of the CDAM on a limited basis. This is a question that can be further researched by comparing more fully the CDAM test with the On-The-Road Exam, similar to studies of Jones et al (1983) and Sivak et al (1981).

Table I DESCRIPTION OF EACH GROUP OF SUBJECTS BY NUMBER, AGE, SEX

GROUP	*SUBJECTS*			*AGE*
	Total	*Male*	*Female*	*Mean Range*
Brain Injured	*28*	*20*	*8*	*17-65*
Able Bodied	*19*	*9*	*10*	*20-66*
Total	*47*	*29*	*18*	*17-66*

TABLE 2

RESULTS OF CDAM SCORES FOR CONTROL GROUP (MEAN +/- 2SD)

Section 1	Section 2		Section 4	Section 5			Section 6	Section
	A	B		A	B	C		
6/6	1/1	2/2	.58±.24 sec	13/13 errors	8±2 lights/secs	1.3	50±9 kph	4/4

TABLE 3

RESULTS OF CDAM SCORES FOR BRAIN INJURED DISABILITY GROUP
(% OF FAILURE)

Section 1	Section 2		Section 4	Section 5			Section 6	Section
	A	B		A	B	C		
0%	5%	33%		33%	61%	30%	53%	76%

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31.4 Joint Controllers For Bipedal Movement For Sitting on a Chair

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and Orthopaedic Surgery*

A feedforward and a feedback controller for the joint movement of a six-link biped model is considered. Two strategies for the computation of the feedback control were utilized. Results of the sitting on a chair motion of the biped, when excited using real subject motion data, showed that the model can predict the experimental contact forces, joint movement and joint moments. Such model should have a feedback mechanism with apriori knowledge of the motion constraints.

This work pertains to understanding control strategies for sitting down on a chair. These control strategies may correspond to those utilized by a human being or may find application in the design of neural or mechanical prostheses.

A six-link planar biped system [1] is considered for analysis and simulation of the sitting-down motion. The experimentally measured normal chair and ground reaction forces are compared with the computed forces for several control strategies. Two control strategies are discussed and reported here.

The system consists of six rigid body links connected through ideal pin joints. The first link is anchored to ground as shown in Figure 1. The links corresponds to the leg, the thigh, the torso, the upper arm, the lower arm, and the hand. At each joint, a moment actuator corresponding to muscles' activities is implemented. For analysis of the sitting-down motion on a chair, additional support is imposed on the system. The chair is assumed to support the biped at single point. This model takes its input, the angular position, from real patient data and computes the moments at the joints and the contact force. Subject motion data were recorded using a Vicon system. Simultaneous measurements of the ground reaction forces at the ground and at the chair, and EMG muscles activities were recorded to check the model validity.

To control the biped model to follow the subject's motion, a feedforward and feedback control was implemented to the model. For the computation of the feedback term, two control strategies were tested. The first strategy is based on the decoupling of the motion of each limb. A full eigenvector-eigenvalue assignment, based on apriori knowledge of the motion constraints, is used to arrive at the second control strategy.

Results of the experimentally measured, and computed chair and ground normal reaction forces are displayed in Figure 2 and 3. The first strategy does not provide a good approximation of the experimental contact forces. The contact occurs after 3/10 of a second of the actual contact. A rapid change in the ground reaction force is also detected. On the other hand, the second strategy gives a good approximation in time and magnitude. The motion data and joint moment computed using the second method also show a good approximation of the experimental data.

A feedforward and feedback mechanism with apriori knowledge of motion constraints seems to show a viable model for the control of a biped model. Such model adequately prescribes motion, torques, and forces of contact.

REFERENCES: [1] H.Kallel, "A six planar biped model for sitting down on a chair and standing up," M.S.

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This work was supported by The Department of Electrical Engineering, Division of Orthopaedic Surgery and The Gait Analysis Laboratory of The Ohio State University, Columbus, Ohio 43210, and NIDRR Grant #H133E80017.

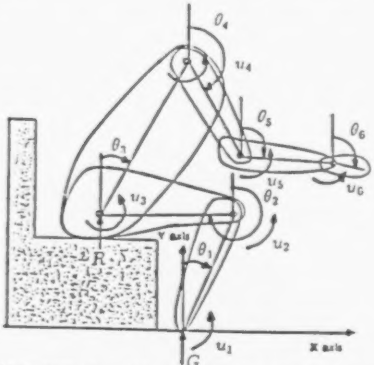
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FIGURE 1: The six link planar biped model

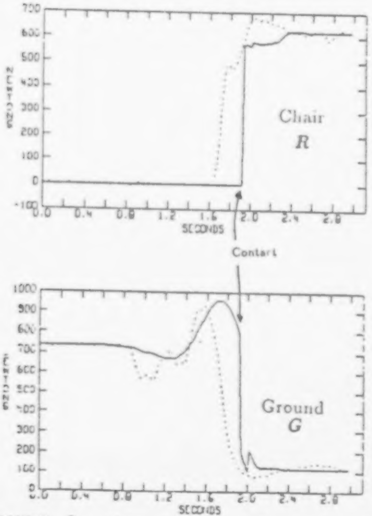

FIGURE 2: Experimental and computed reaction forces (strategy 1)

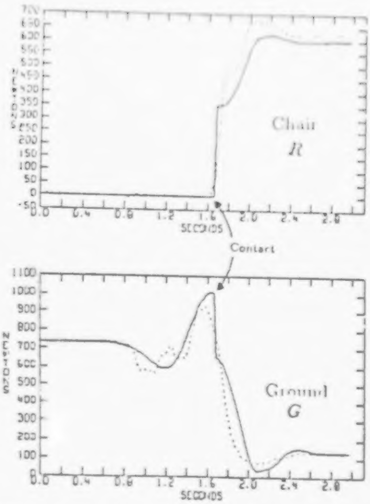

FIGURE 3: Experimental and computer reaction forces (strategy 2)

31.5

QUANTITATIVE MEASURES OF HAND/WRIST MOTION

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ABSTRACT:

The purpose of this research was to quantify the wrist motion measures of normal persons. A wrist monitor was constructed to measure wrist angle, angular velocity, and acceleration in both the radial/ulnar and flexion/extension planes. The wrist monitor was validated by collecting wrist motion data from three normal subjects indicate that maximum angular velocity and acceleration in the flexion/extension plane are approximately 800 deg/sec and 5000 deg/sec^2. Preliminary motion from one subject indicates that maximum velocity and acceleration in the flexion/extension plane is about twice that in the radial/ulnar plane.

INTRODUCTION:

Hand and wrist injuries have been recognized as a problem which severely affects the ability of the sufferer to lead a normal life. Hand and wrist problems are also one of the leading causes of occupational disability in the United States. These problems affect the sufferer in several ways, including 1) interfering with work tasks, 2) interfering with household tasks, 3) severely diminishing quality of life, and 4) pain.

The ultimate purpose of this research was twofold. First, quantify wrist motion measures, such as angle, velocity, and acceleration, of injured or disabled persons to diagnose the degree of injury. Second, use these wrist motion measures to assess the rehabilitation progress of injured persons.

In order to accomplish these goals, a database of wrist motion measures of normal subjects needs to be compiled for comparison.

METHODS:

Subjects

Four right-handed, healthy subjects (age 22-30; 3 males, one female) volunteered as normal control subjects in this preliminary research.

Apparatus

A wrist monitor was developed and constructed in the Biodynamics Laboratory that measures wrist angle, angular velocity, and acceleration in the radial/ulnar planes and flexion/extension planes. The monitor is an aluminum device that has two potentiometers centered over the wrist's points of rotation in the radial/ulnar and flexion/extension planes. The two potentiometers are orthogonal to each other, and they record wrist motion measures in their respective planes independently. The wrist monitor is strapped to each subject's forearm with a premolded Orthoplast cuff.

The potentiometers' voltages were monitored by a Labmaster A/D converter, and the data were stored on an portable Compaq computer. After the voltages were converted into wrist angles, the angle data were differentiated once and twice to calculate angular velocity and acceleration, respectively. The data were smoothed three times by a normally distributed smoothing function before each differentiation.

Procedure

The wrist monitor was strapped to the right forearm of each subject and adjusted to each subject's wrist points of rotation. Static angle data were collected while each subject rotated his/her wrist at the maximum static angles of flexion, extension, radial deviation. For three subjects, dynamic motion data were then collected from movements in the flexion/extension plane in which each subject was asked to move his/her hand as fast as possible. For one subject, dynamic motion data were collected in both the flexion/extension and radial/ulnar planes.

RESULTS:

The maximum static angular deviations in the flexion/extension and radial/ulnar planes agree well with data in the published literature.

Maximal angular velocity and acceleration data in the flexion/extension plane of three subjects are shown in Table 1.

MEASURES OF HAND/WRIST MOTION

The maximal angular velocity and acceleration data in the radial/ulnar and flexion/extension planes of one subject are shown in Table 2. The flexion/extension motion measures are about twice as high as the radial/ulnar data.

CONCLUSIONS:

The data collected from four normal subjects in this research show the ranges of maximal velocity and acceleration in the wrist planes of motion. These preliminary data will be used to build a database of wrist motion measures for normal control subjects. Ultimately, wrist motion measures from injured or disabled persons will be compiled and compared with that of normal persons to assess degree of injury and rehabilitation progress.

Table 1. Peak velocity and acceleration in the flexion/extension plane for three subjects.

Subject	Peak Ang. Velocity (deg/sec)	Peak Ang. Acceleration (deg/sec)
GM	799	4936
CH	880	5440
CS	789	4432

Table 2. Peak velocity and acceleration in the radial/ulnar and flexion/extension planes for one subject.

	Peak Ang. Velocity (deg/sec)	Peak Ang. Acceleration (deg/sec)
Radial/ulnar	350	2198
Flex/ext	799	4945

This project has been support by NIDRR Grant #H133E80017.

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31.6 AN EVALUATION PROGRAM EXAMINING TWO EXPERIMENTAL WALKERS

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ABSTRACT

Walkers are important yet poorly understood assistive devices. Last year, an evaluation project was described which focused on two experimental walkers. This project examined these walkers from numerous perspectives to ascertain possible differences in relation to functional criteria. Results from this two phase study suggest that the experimental four-wheeled walker had significant impact on mobility and gait. This is contrasted to findings suggesting that perceptions concerning the functional improvements were equally divided between the two walkers.

INTRODUCTION

Long term usage of various forms of walkers suggest the need for assistance either in supporting oneself due to loss of functioning in the lower extremities, or problems associated with maintenance of balance. However, due to present design of more commonly used walkers, limitations appear to occur in mobility, specifically speed and maneuverability. These issues in turn impact upon the individual's quality of life usually directly by shrinking the lifespace s/he may now engage. This likely has direct effects upon one's sense of isolation and independence.

The Harrington Center began an evaluation study examining a modified two-wheeled walker and a four-wheeled walker with hand brakes. A multi-disciplinary team assembled a two phase program where the first phase consisted of a short-term intensive cross-sectional study of the two walkers; the second phase used a longitudinal perspective.

METHOD

A combination of standardized and unstandardized questionnaires were used in both phases of the project. These included (1) the Arthritis Impact Measurement Scales (AIMS), (2) the Arthritis Helplessness Index, and (3) the Harrington Walker Questionnaire. These measures were used to assess functional capabilities, psychological variables, and various global and specific perceptions related specifically to the walker's functional performance.

Objective and observational measures were also used. These included walktimes and steps taken during a fifty-foot walk, and ratings made on the individual's performance while the participant used the four-wheeled walker on a practice course.

A biomechanical assessment was made on second phase participants and focused on (1) motion analysis, (2) assessment of joint forces, and (3) inspection of muscle activity through EMGs.

Product analysis was conducted by an industrial designer who videotaped individuals in their homes while using the four-wheeled walker. This allowed for ecological identification of problem areas while using the walker as well as supplying data for proposed modifications in product design.

RESULTS

The four-wheeled walker allowed participants to walk significantly faster compared to their current walker during the first phase of the project. Second phase participants showed significant improvements in the number of steps taken compared to their current walker during the fifty-foot walk.

Moderately high levels of difficulty were detected on the practice course areas which involved simultaneous activities; these included: (1) Opening/Closing Doors and (2) Self Transfers. Trouble maintaining stability of the walker while attempting another activity suggests the need for a stable braking mechanism.

During phase one, the four-wheeled walker was perceived as performing significantly better going up and down ramps compared to one's current walker in several areas. The four-wheeled walker was viewed as less difficulty, safer, and requiring less assistance. Significantly less pain was found in the shoulder area.

During phase two, the four-wheeled walker was perceived as being significantly safer going down (but not up) ramps compared to one's current walker. In addition, going over sidewalk cracks was perceived as being significantly easier and safer with the four-wheeled walker.

In contrast to phase one findings where significantly less pain was found in the shoulder area while using the four-wheeled walker, significantly less pain in the back area was found when using the four-wheeled walker.

A significant different was found on the Mobility scale of the AIMS indicative of better mobility with the four-wheeled walker.

Relatively good upper body strength appeared to be associated with positive performance with the four-wheeled walker, whereas poor performance occurred when upper body strength was lacking.

DISCUSSION

This evaluation of two experimental walkers focused upon three types of data to determine the realtive strengths and weaknesses as compared to one's current walker. These data involved objective measurements, observational ratings and self-report surveys. Together, there appears to be some immediate and longitudinal benefits experienced when using the four-wheeled walker. These involve increases in speed, better handling on ramps, and decrements in pain. Some problems were noted in maneuvering the four-wheeled walker in regards to specific situations.

This evaluation methodology has some advantages. In contrast to examining differences between two independent groups, a within-subjects design allows comparisons using the individual as their own control. The usage of different types of data enables researchers to construct and examine a pattern of results. This triangulation among different types of data and variables provides a better clinical picture than individual findings.

This study should be regarded as primarily exploratory for several reasons:

(1) The number of participants was small.

(2) Participants were self-selected when entering the study.

(3) The saliency of ratings concerning one's current walker is questionnable. This has to due with differences in immediate versus distant experiences.

We are indebted to Guardian Sunrise Medical, Inc. for their support on this project.

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32.1

CONTENT ANALYSIS OF RESNA PROCEEDINGS

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ABSTRACT

Presentations at RESNA annual conferences from 1983 through 1988 were analyzed by their content. The relative frequency of six basic characteristics were developed. These characteristics were: Disability, Life Function, Outcome, Process, Affiliation, and Funding.

INTRODUCTION

As part of a project to determine the current and potential scope of the rehabilitation engineering profession, an analysis of the RESNA proceedings from 1983 through 1988 was performed. As with any developing discipline, there is bound to be considerable uncertainty to self identity and questions as to the nature of the content and form of the practice of the discipline.

METHOD

The analysis examined six basic characteristics of RESNA Proceedings publications: the Disability and Life Function addressed (Figure 1), the Outcome resulting and the Process through which it was achieved (Figure 2), the professional Affiliation of the authors and the Funding source (Figure 3). Every presentation (a total of 1,364) was evaluated in each of these categories. Each characteristic was divided into several types or classes. A presentation could be scored in more than one class; therefore, the totals do not sum to 100%. Most of these classes are self explanatory. These were:

Disability or Handicapping Condition

What type of functional limitation did the publication address?

General- general functional limitation of any kind.

Mobility, Wheeled- barriers or problems faced by persons using wheelchairs.

Mobility, Ambulatory-

Dexterity- the manual manipulation of objects.

Communication- difficulties in expressive communication.

Other-any disability not included in another category.

Hearing-

Vision-

Pain-

Cognitive/Mental-

Respiration-

Area of Life Function Addressed

In what area of life did the individual or individuals encounter a limitation that was addressed in the publication?

Independent Living- self determination and independence in daily living activities including mobility.

Medical or Health- basic health issues not part of the disability.

Vocational-

Other-

Safety- reduction of hazards to individuals with disabilities.

Recreation-

Transportation- mobility within the community, both public and private transportation.

The Outcome or Result of the publication

What is the result described by the article?

Assistive Device- the application of a mechanical or electronic device.

Evaluation- a method or technology for evaluating, diagnosing, or measuring the capability of an individual. The results of an evaluation were used by someone other than the individual evaluated.

Therapy- a therapy, training, or procedure that directly altered the behavior of the individual with a disability.

Service Delivery- a system that delivered services or products to an individual with disabilities.

Contribution to Science- a contribution to our knowledge of the characteristics of a particular type of disability or the characteristics of the environment in which the individual must function.

Other-

The Process through which the result was achieved

What method did the authors use to produce the result of the publication?

Case Study- a description of a particular situation.

Experimental- the collection of data and formal hypothesis testing.

Design Process- creative problem solving.

Position Paper- the opinion of the writer with a focus toward basic value questions.

Other-

Affiliation or organization supporting the result

Where were the authors employed?

Rehabilitation Facility- a not for profit rehabilitation facility; such as, an REC or rehabilitation institute or hospital.

University-

Independent Developer- independent practitioners not affiliated with other organizations.

Corporation- a for profit corporation.

User-

The Source of Funding for the result

Where did the funds to support this result come from?

Public Disability Targeted-federal, state, or local funds specifically targeted to disability related research or service delivery.

Not Available-

Public, General-federal, state or local funds not specifically targeted to disability issues.

Corporation-

User-

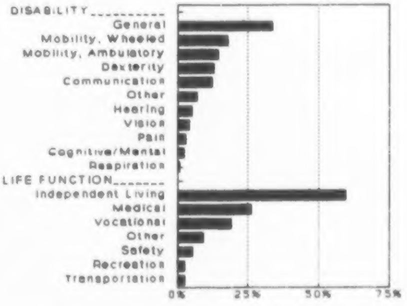

Figure 1. Relative frequency of presentations by Disability categories and Life Function Categories.

RESULTS

Figures 4, 5, and 6 indicate the relative frequency with which presentations concerning Independent Living, Medical, and Vocational themes included particular disability classes, yielded a particular result, and used a particular method for developing the result. Figures 7, 8, and 9 indicate the relative frequency with which presentations concerning a particular form of outcome also dealt with a particular class of disability, life area, and used a particular method for developing the result.

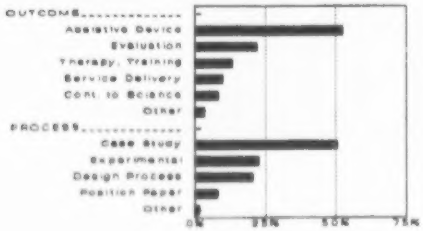

Figure 2. Relative frequency of presentations by Outcome categories and Process categories.

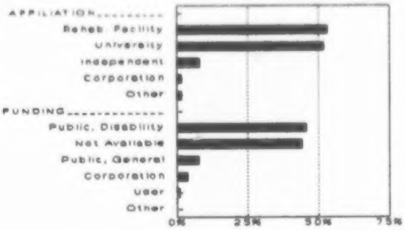

Figure 3. Relative frequency of presentations by author Affiliation categories and Funding source categories.

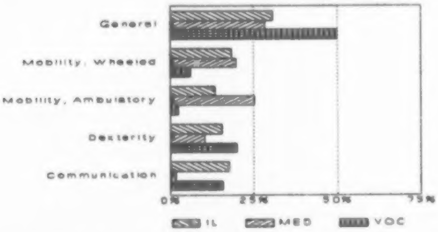

Figure 4. Relative frequency of presentations referencing disability categories given that the area of Life Function addressed was Independent Living, Medical, or Vocational.

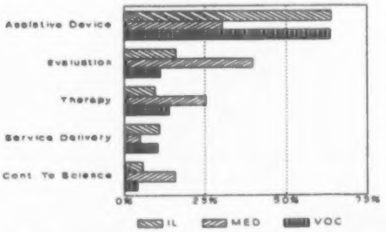

Figure 5. Relative frequency of presentations producing a particular result given that the presentation addresses a particular area of Life Function; Independent Living, Medical, or Vocational.

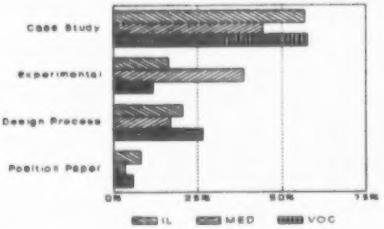

Figure 6. Relative frequency of presentations using a particular method given that they were directed toward a particular area of Life Function; Independent Living, Medical, or Vocational.

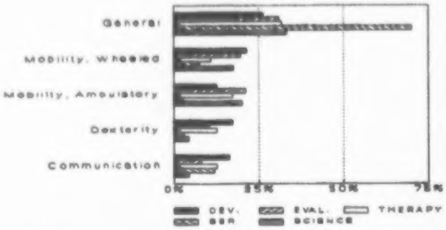

Figure 7. Relative frequency of presentations concerning a particular Disability class given that they produced a particular type of Outcome; Device, Evaluation, Therapy, Service System, or contribution to Science.

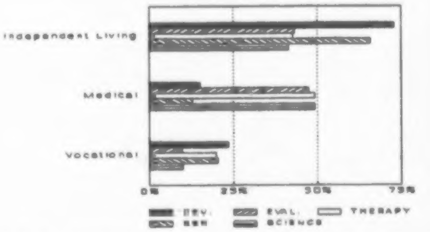

Figure 8. Relative frequency of orientations addressing a particular area of Life Function given that they produced a particular type of Outcome; Device, Evaluation, Therapy, Service System, or contribution to Science.

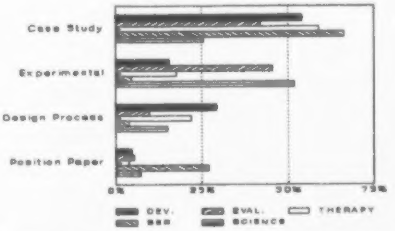

Figure 9. Relative frequency of presentations using a particular category of Process given that they produced a particular type of Outcome; Device, Evaluation, Therapy, Service System, or contribution to Science.

32.2

A PREDICTIVE MODEL FOR PERSONAL ASSISTANCE NEEDS FOR THE DISABLED PERSON

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ABSTRACT

An estimated 4.9 million Americans need some assistance in carrying out daily activities. However, no procedures were found that allow consumers to objectively determine the quantity of personal assistance they may require. The Wichita REC has created a database of personal assistance needs over a two year time span of a limited population of consumers in an independent living environment. These data were grouped according a mobility code, a probability density function found to fit each group, and limits of personal care requirements at the 90% confidence level determined. These limits were found to be too broad and overlapping to be of much assistance to the individual consumer except for gross estimates. A new model based on a self-determined capability level and regression analysis was derived. This model indicates better estimates than previously obtained.

INTRODUCTION

An estimated 4.9 million Americans need some assistance in carrying out daily activities. There were, however, no procedures found that allow consumers to objectively determine the individual quantity of personal assistance required. In addition, no methods were found to assist funding agencies (i.e., state governments, federal governments) in determining the total resources required for personal care to assist their population of disabled persons at the level required to become independent and employable. It is expected that the results of this research will provide state and federal agencies and the consumer the information required to predict the funding needed to provide this personal assistance.

The population served by the Wichita REC primarily consists of brain damaged individuals, developmentally disabled or through trauma. Persons served are primarily those individuals with cerebral palsy; however, persons with multiple sclerosis, muscular dystrophy, Friedreich's Ataxia, spina bifida, and post trauma brain damage are also served. The population consists of normal to near normal intelligent individuals who desire the independence that a job and their own apartment afford.

DATABASE INFORMATION

A database system has been created by the Wichita REC (1,2,3) for the PC or XT compatible computer comprised of the quantity of attendant care provided for people with disabilities living at Timbers. A client specific database has been created containing specific information such as demographics, financial information, self-mobility and disabilities for each client. The self-mobility field classifies the client according to their physical capability to move in their living environment. These classifications range from ambulatory to aide assisted movement. The information from this database for the years 1986 and 1987 including the mobility code for the client was translated into a spreadsheet file to do statistical analysis and to produce graphical displays of the results.

MOBILITY CODE MODEL

The histogram information obtained can be converted into a probability with the average daily time of care being the random variable. Probability density function models were fit to these event probabilities. The Rayleigh density function was chosen for mobility code C because it is only valid for positive values of the random variable, because of its steep slope at the origin and its infinite tail or shallow slope for large values of the random variable. The Maxwell density function was chosen for mobility code E because it also was only valid for positive values of the random variable but it had a zero slope at the origin followed by a steep slope and an infinite tail or shallow slope for large values of the random variable. The Gaussian density function was chosen for mobility code F because this code was represented by only one client with many client weeks of service provided.

When analyzing the three density functions, it is noted that the functions corresponding to mobility codes C and F are reasonably disjoint functions. However, the function corresponding to mobility code E overlaps both of these functions. In addition, when 90% confidence levels are chosen for determining the estimated level of personal care required for an individual in one of these three mobility codes, mobility code E contains most of the other two codes.

MULTIPLE VARIABLE REGRESSION MODEL

To determine a better model for predicting attendant care needs, capability levels were established for each of six body areas: the head and neck; the body trunk; the left hand and arm; the right hand and arm; the left leg and foot; and the right leg and foot. The four classifications for each body area were assigned a number with "Normal" being assigned a weight of 3 down to "Non-functional" a weight of 0 as the individual's capability level. These six weights are, in some sense, a measure of the individual's capability level. Since the performance of many tasks do not depend on right arm or left arm capability but rather on a measure of single arm capability or on a composite capability, these two measures were combined as quadrature components into a single measure. The same procedure was followed for the legs and for the neck and body. In addition, it was hypothesized that the quantity of personal assistance required for an individual would be inversely proportional to this capability. Therefore, each of the pairs of parameters mentioned were combined into a composite model parameter according to the following relationship where X_i represents the $i^{\underline{th}}$ regression variable.

$$X_i = \frac{1}{(1 + P1^2 + P2^2)^{1/2}}$$

These data were then correlated using a 3-way regression analysis with three parameters describing the individual's capability level as the independent variables. From this analysis, a predictive model was generated to estimate, based on the individual's capability parameters, the average amount of daily care required by the individual.

CONCLUSIONS

The results of the inverse linear regression model shows relatively good prediction of the expected average of daily personal assistance required by a person with disabilities. In about 60% of the cases tested, the model error was less than 1 hour per day relative to the actual care required. However, there were some very disturbing large errors exhibited in a few cases. One individual used about 2 hours less per day of personal assistance than predicted by the model while another individual used about 2 hours more than predicted. Both individuals were of similar capability based on the regression variables calculated. It should be noted that the regression model did not include any measure of the individual's management skills or the relative importance the individual placed on keeping the number of hours of personal assistance needed to a minimum. This discrepency in prediction points out a difference in intent for model results. The third-party provider such as the state or federal funding agency places the highest priority on reducing the cost of personal assistance. The consumer, however, may consider time management more important than cost of service. Utilizing personal assistance for a task such as dressing may reduce the time required for this task by a factor of 4 (i.e. from an hour unassisted to 15 minutes with assistance) and allow more time for studing school subjects or earning a living. Thus the quality of life is increased for the consumer but the cost of service is increased for the third-party funding agency. In order to address some of these issues, a self-administered survey is currently being designed to place a measure on some of these more subjective parameters. It is expected that these new measures will allow greater accuracy of prediction without losing consumer self-management of their life.

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Survey of Seating Providers for Patients with Traumatic Brain Injury

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ABSTRACT

An informal survey of 14 US providers of seating for patients with traumatic brain injury indicated that challenges exist because of the rapidly changing needs of this population. Head positioning was the major problem. The survey results suggest the need for further investigation.

INTRODUCTION

In the last three years we have begun regularly providing seating systems for traumatic brain injued (TBI) patients. Our local experience as well as the experience of other seating specialists we have talked to indicated that the frustrating problems we have encountered were common ones. As a first step in better understanding TBI seating, its problems and possible solutions, we conducted an informal telephone questionnaire of 14 US service providers.

Facilities were selected because we knew that either the staff were pioneers in TBI seating provision (i.e., Chicago Rehab Institute), or provided volume seating for many disabling conditions including TBI (i.e., Miller's), or regularly provided rehab services including seating for TBI wheelchairs users (Braintree) Figure 1.

RESULTS

Patient profile

The 14 polled facilities saw a total of 81 new TBI seating patients a month for an average of 5.8/month.

The majority (10) reported that they first worked with their mainly adult patients when the patients were medically stable and ready for rehabilitation, 3-9 months post injury. The patients were described as ranging/fromcomatose to alert. Two facilities reported that the disability level of their patient population varied over time as did the number of those with challenging seating problems. Only two facilities attempted an estimated of the percentage of challenging (high tone/severe deformity) patients (10%, 33%).

A few of the facilities were beginning to seat the patients earlier, one even berfore the patients was transferred to a rehab setting from acute care. Early intervention was credited with the prevention of severe contractures and postural deformities commonly seen in TBI nursing home patients who are several years post injury.

Facility	Type	Respondent	Estimated No. of New TBI Seating Patients/Mo.
Rancho Los Amigos Hosp. Downey, CA	In Patient Rehab. Hospital	PT Clerk	3 - 4
Sharp Memorial Hospital San Diego, CA	In Patient Rehab. Hospital	Rehab Eng./OT	4
Rehab. Institute of Chicago Chicago, IL	In Patient Rehab. Hospital	Rehab. Eng.	5 - 10
Braintree Hospital Braintree, MA	In Patient Rehab. Hospital	PT	10
Mary Freebed Hospital Grand Rapids, MI	In Patient Rehab. Hospital	PT	3
Baptist Regional Rehab Ctr. Memphis, TN	In Patient Rehab. Hospital	OT	2
Visitors Hospital Buchanan, MI	In Patient Rehab. Hospital	PT	5 - 10
Head Injury Ctr. @ Lewis Bay Hyannis, MA	In Patient Rehab. Hospital	PT	< 1
Memorial Hospital South Bend, IN	In/Out Patient Rehab. Hosp.	Rehab Eng.	4
Cerebral Palsy Res. Ctr. Wichita, KS	Out Patient Seating Prog.	PT	< 1
Wheatridge Regional Ctr. Wheatridge, CO	Central State Rehab. Facility	OT	15 - 20
Miller's Special Products Akron, OH	Equipment Dealer/Manufacturer/ Seating Service Provider	OT	4 - 5
Rehabco Bronx, NY	Equipment Dealer/Seating Service Provider	Rehab Specialist	3 - 4
Samaritan Health Services	Equipment Dealer/Seating Service Provider	Rehab Specialist	10 - 15

Figure 1. Facilities Surveyed

Strategies for addressing the needs of a changing patient
Abnormal tone and postural changes, week to week or more commonly, month to month challenged 13 of 14 clinicians and DME vendors and providers to devise strategies to meet the resulting seating needs. Most (6) initially fit the patient with trial or loaner equipment, often from an accumulated inventory. Once the patient's condition stablized and/or upon discharge a definitive system was provided. Problems with this method included excessive staff fabrication time expended for often makeshift trail equipment. One respondent reported that a trial system is typically adjusted 5-20 times during his patient's 5 week rehabilitation stay. Two respondents were not reimbursed for this work. Three, in an attempt to minimize the amount of trial equipment, provided the definitive system as soon as possible and removed system components if there was an improvement in the patient's condition. A planar seating system, which is more accommodating to postural changes than custom contoured seating, was favored by proponents of this strategy. Four facilities used or have used adjustable seating systems (i.e., E & J Postura, Theradyne Posture Care). Most reported durability problems resulting in the chairs often being out of adjustment and that the chairs could not accommodate many of the severe patients. One facility (Braintree) who employed a conscientious person to maintain their equipment reported no durablity problems with their adjustable system.

Six facilities used custom contoured seating (i.e., foam-in-place, vacuum consolidated beads) in conjunction with planar and/or adjustable systems. Two facilities wanted to try these systems in the future while two others had had problems with them.

Wheeled bases
Ten facilities reported use of reclining wheelchairs. Four explained that most patients initially seated in a recliner improved enough to be provided a standard chair, often an ultralight, upon discharge. Four have also used tilt-in-space or fix position reclining bases and three would like to try them.

Seating problems encountered
Problems with head and lateral trunk control were the most common (Figure 2). Head support was also the most difficult positioning problem for 11 facilities. Six use a combintaion of commercial, modified commercial, and hybrid systems. Two facilities have used or have tried as many as 6 different approaches. In addition to failing to provide proper head support, respondents complained that some of the devices they are using or have used allowed patients' heads to become wedged under the headrest laterals, are too restrictive, block vision, may cause choking, and are ugly.

Pressure sores were not a big concern. Four facilities reported using pressure relieving seat cushions "occassionally" or "5-10% of the time". Three facilities had difficulties seating people with tight hamstrings. Overall 10% of the patients were reported to have tight hamstrings preventing their feet from reaching the wheelchair foot plates.

No. of Facilities	Reported Problem Areas
	Head Positioning:
11	- general
8	- anterior support
4	- lateral support
2	- neck hyperextension
	Lateral Trunk Supports
11	- general
7	- won't stay in position
7	- too small, wrong shape
3	Sacral sitting, sliding out of seat
3	Tight hamstrings

Figure 2. Problem Areas Reported by TBI Seating Providers

DISCUSSION

As indicated above, this was an informal survey intended to give us a rough idea of the state-of-the-art of TBI seating in the U.S. The results should be interpreted with this in mind. Further, more structured surveys are required. However, based on consensus responses to certain questions we are confident that further studies will confirm that most service providers are challenged by the rapidly changing needs of the TBI patient especially regarding head positioning. The respondents, including ourselves, felt the need for information regarding why many TBI patients develop abnormal head posturing and how to determine the appropriate amount of external support. More information is also needed regarding the efficacy of early post injury seating and positioning as a way to minimize contractures and abnormal tone.

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We thank the survey participants for their thoughtful responses and insights.

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32.4

REHABILITATION TECHNOLOGY AND SUPPORTED EMPLOYMENT: HOW IT'S WORKING IN KANSAS

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ABSTRACT

Kansas is one of 27 states which has been awarded money by the U.S. Department of Education to establish supported employment programs. A unique feature of the supported employment grant in Kansas is the inclusion of rehabilitation engineering services. While other states have utilized rehabilitation engineering in placing individuals in supported employment; few, if any, have funded rehabilitation engineering within the demonstration grant.

BACKGROUND

The intent of supported employment is to render individuals with severe disabilities, previously considered nonfeasible for competitive employment, to be productively employed in the community. It targets individuals who require ongoing support services to perform competitive work.

The five-year Kansas supported employment demonstration grant, the Supported Employment Initiative of Kansas (SEIK), began in 1986 with nine pilot sites. Currently 14 sites have received funding under the SEIK grant. The work performed at these sites varies from janitorial and clerical work to work in food service and manufacturing.

METHODS

Under the SEIK grant, problems are identified by those individuals who work directly with clients at the worksite, or job coaches. The worksite is examined by the rehabilitation engineer, and the client's performance on the job is observed. Recommendations are made on appropriate work arrangement. Worksite modifications or adaptive devices are designed and fabricated and delivered to the worksite. Job coaches are instructed in the use of modifications where necessary. All expenses for rehabilitation services are provided free of charge under the SEIK grant.

RESULTS

In the first two years of the SEIK grant, rehabilitation engineering has provided over 50 devices to eight project sites. In most cases, the devices have remained relatively simple from an engineering standpoint. The majority of the clients at these project sites are mentally retarded; and as such, most of the devices seek to remove some of the cognitive requirements of tasks. Many of the devices fall into three categories: modifications to assist with (1) counting, (2) sequencing of parts, and (3) alignment.

Figure 1 shows an example of a device to assist with the counting requirements of a job. This job required the packaging of 95 spools. A large, flat counting board could have been utilized. However, the counting jig seen in figure 1 allows only 95 spools to fit on the 5 dowels while only requiring 1/2 sq. ft. of table space.

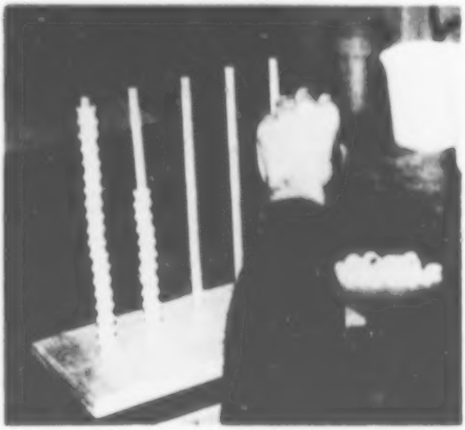

Figure 1
Spool Counting Jig

Figure 2 illustrates a device required to force sequencing of parts. The plastic parts seen in the figure are guides for film processing equipment which clients had difficulty assembling correctly. The wooden jigs in figure 2 make certain that the triangular plastic parts are correctly assembled with the rectangular film tracks.

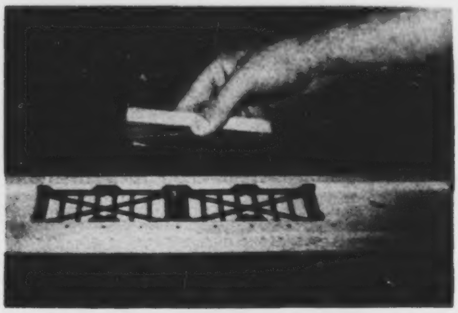

Figure 2
Assembly of Film Tracks Using Jig

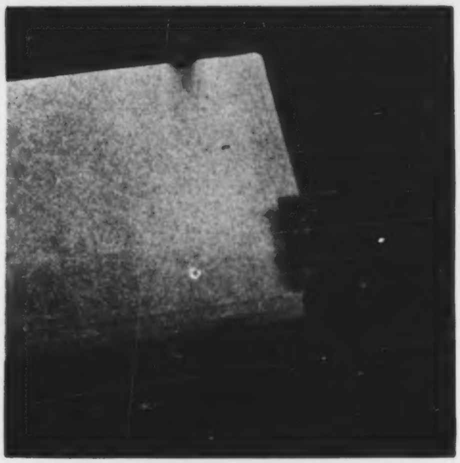

Figure 3
Folder Labeling Fixture

A modification to assist in alignment and proper orientation of parts is shown in figure 3. This device was designed for a job which required label placement on file folders. Four different labels were to be placed at different locations on the edge of these folders. Clients had difficulty placing the labels neatly on the folders and in proper sequence. On the fixture in figure 3, guides assist in locating a label on the teflon lever. Guides also ensure that the folders are properly held in place. The lever arm with the label in place is then lowered alongside the folder, and the label sticks to the folder at its proper location.

CONCLUSIONS

Most supported employment programs are based on the premise that through training and the on-going support of a job coach, persons with severe disabilities can be competitively employed in the community. The Kansas grant has also demonstrated the utility of a non-behavioral approach, namely, the technical assistance of rehabilitation engineering in supported employment.

ACKNOWLEDGEMENTS

The authors wish to acknowledge Carolyn Bayless, SEIK Project Coordinator, and the State of Kansas, Department of Social and Rehabilitation Services for supporting this project. They further wish to thank the Cerebral Palsy Research Foundation of Kansas (CPR) for its continued support of programs to improve the quality of life of persons with disabilities. Special thanks to Meighan Keely of CPR for her research assistance.

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32.5

A Basis for Assessing Need for Assistive Technology Services in Vocational Rehabilitation

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This paper describes a method used in the State of Washington to establish a basis for planning assistive technology services. The method included evaluation of departmental statistics and interview or survey of counselors, administrators and consultants.

Amendments to the Rehab Act in 1986 required that:

1. Vocational Rehabiltation agencies must include in their state plan a description of how rehabilitation engineering and technology will be provided to its clients.
2. Rehabilitation technology evaluation must be provided, as necessary, to assess and develop the capacity to do work.
3. As appropriate rehabilitation techno-logy services must be provided as a voca-tional rehabilitation service and by qualified individuals.
4. If rehabilitation technology services are needed, they must be identified in the Individual Written Rehabilitation Plan (IWRP).

These amendments created a good deal of apprehension about how state agencies would appropriately meet the requirements. However, these changes also provided the first serious mandate in the rehabilitation community to develop a delivery system for Assistive Technology Services (ATS). The amendments also created great new opportunities to serve the needs of working aged disabled persons. "This is the first time I remember a change in the law that gives us new and better ways to do our job rather than to give us greater and more difficult responsibilities" said a Washington State Vocational Rehabilitation Administrator.

Establishing the most appropriate methods for delivering services should be based on some form of need assessment. Through a contract with C.Gerald Warren & Associates the Washington State Division of Vocational Rehabilitation performed an analysis of need and expectation for assistive technology. The following is a summary of methodology used in that study.

Departmental statistics were used to describe the distribution of disabled clients being served and to analyze the progress of clients through the rehabilitation process. Perspectives of the "players" in the agency was determined by interviewing a sample of twenty-five line counselors, and surveying administrators and medical social work consultants to determine their views of how Assistive Technology might benefit clients. Counselors were also asked a set of questions about their use of assistive technology with clients who had specific disabilities.

From the 26 federally defined disability categories the following 13 groups were selected to provide a list of those groups which would have the greatest potential to benefit from ATS. This sample was evaluated in many ways including number in open status on a specific date and number closed during a 6 month period. The percentages represent 6,065 clients in open statuses and 4,211 in closed statuses.

	Open (%)	Closed (%)
1. Visual Impairment	1.7	2.3
2. Hearing Impairment	12.4	11.9
3. Cerebral Palsy	1.6	2.5
4. Congenital Malform.	4.4	4.1
5. Neurological	2.8	2.7
6. Arthritis/Rheumatism	7.3	6.3
7. Head Injury/Stroke	2.5	2.3
8. Polio, MD, MS, etc	4.2	3.3
9. Spinal Cord Injury	5.1	4.0
10. Other Orthopedic	45.7	43.9
11. Amputations	1.9	2.7
12. Mental Retardation	10.2	13.4
13. Speech Impairment	0.4	0.5

The sample was evaluated for distribution between Rural and Urban settings.

The sample was also evaluated for its distribution between severe and non-severe disability. Federal definition of severely disabled is as follows:

1. Loss of function must be permanent and result in at least one of the following following limitations:
    a. Preclude regular use of bus or train train
    b. Unable to perform sustained work activity for six hours or more
    c. Disfigurement and/or deformity so pronounced as to cause social rejection.
    d. Unable to climb one flight of stairs or walk 100 yards on level without pause.
    e. Loss of manual dexterity or coordination.
2. Client will most likely require multiple VR services over an extended period of time.

Federal regulation defines 18 statuses of service, 11 open statuses and 7 closed. Though it is argued that these statuses are poor indicators for program evaluation, they are all that is available. The following is a complete list of the statuses.

Status	Description
00	Referral for services
02	Application and eligibility determination
06	Extended Evaluation - to determine eligibility
08	Closed - not eligible
10	Rehabilitation Plan Development
14	Counseling in Preparation for Employment
16	Medical Restoration
18	Training
20	Ready for and actively seeking employment
22	Successfully employed and job fit is being analyzed
24	Services are interrupted
26	Closed - Successfully employed
28	Closed - Not employed after services have been provided
30	Closed - Not employed and no services have been provided
32	Post employment services (PES) services provided after client is successfully employed
35	Closed - from PES
37	Closed - from PES and moved to referral status
39	Closed - from PES for other reasons

To make some determination of whether severely disabled clients were becoming "stuck" in a particular status, staff provided a definition of extended time in status as follows: status 06, greater than seven months, status 10, greater than four months; status 18, greater than 14 months; and status 20, greater than 16 months.

With the definitions and categories established, i.e., disability categories; statuses, open and closed; severity and the extended time in status, we were able to perform a wide variety of cross tabulation in order to look for people in status or categories who would be most likely to benefit from ATS. This included categories with relatively large numbers of clients in open status for prolonged periods of time, those which had high rates of closures before rehabilitation and those who were closed but not employed. A second objective was to identify the statuses in which the use of ATS were most appropriate.

Phase II of the project involved determining how staff and administrators viewed ATS. This was conducted through interview and survey techniques. The survey was designed to collect information in six areas. First staff were asked to identify the frequency with which clients were delayed in their program due to a variety of factors that could potentially be solved by using ATS. The same set of questions was asked about clients who were closed but not employed. Next they were asked how often they had used ATS in closing cases. They were also asked to identify the frequency with which they would expect ATS to be used in post employment services. They were asked to "reveal" whether or not they felt that severely disabled clients had been turned away because no appropriate intervention could be identified. They were provided a matrix with functional limitations on one axis and disability categories on the other. They were asked to mark the matrix to indicate which functional limitations they attributed to each disability category. They also indicated which limitations they felt were amenable to ATS and finally whether they were important functions for return to work. In the last section they were asked about their past use of ATS, to provide examples and to indicate who it was that stimulated the intervention.

Each of the staff counselors was also asked to review specific clients with the interviewer. The counselor was asked to describe the client's physical limitations, to identify the primary problems with proceeding with the client's rehabilitation plan, what the reasons for closures were and if the client was closed rehabilitated what were the technical services, if any, that were utilized.

This methodology produced a great deal of useful information that served as a basis for program planning and markedly increased the sensitivity of the agency to its past, current and future use of Assistive Technology Services.

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33.1

KATDAS; A SMALL NUMBER OF KEYS DIRECT ACCESS SYSTEM

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ABSTRACT

Speed and message content are two major aspects of communication research. Speed is often determined by the controllability of the input device. This paper presents a method of character entry which allows for a direct-access-like entry system with a small keyboard (twelve-key system called Katdas). The principle is based on analyses by Minneman and others (1, 2). The system can be placed between a single key operated scan system and a multiple key conventional entry system. The results of laboratory experiments with this system, i.e. speed, errors and learning, are discussed below.

INTRODUCTION

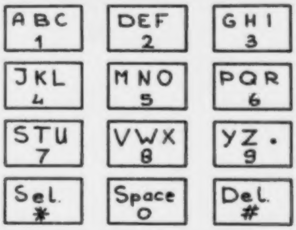
The use of a technical communication system, means that a large number of switch or key selections has to be made to compose a message by means of characters or select a message previously made up or stored. The control part of an aid is often a limiting factor in the production of messages. Considered from the viewpoint of information theory, the information output rate is low for many users. In case of the motory handicapped user, the remaining control functions have decreased thereby lowering the maximum information output-rate. If we consider the motoric ability (and impairments) of a user as a fixed condition, the research and design problem is to exploit this as well as possible. There is a need for entry systems ranging between single key operated systems and full size keyboards which have sufficiently large key operation areas (3). This paper describes a 12-key system which almost acts as a direct access system. Prior to this description, we will place the 12-key system in a model of communication systems.

MODEL OF A COMMUNICATION AID

In general, the following hardware elements can be found in a communication aid:
A control element and filter element is the switch, joystick or some control device from which the output can be filtered. The third element is the conversion of the filtered control signal into an actual selection, i.e.: control of scanning or multistep selection. The fourth step includes expansion of entered communication elements or prediction of the next element. Elements can be characters, parts of words, words, sentences or complete messages. The resulting sequence of communication elements is prepared for proper output in the fifth step and printed, displayed or spoken in the last step. Katdas relates to the third step; it can be seen as a decoding principle which transforms input commands into selections of communication elements.

KATDAS

The word KATDAS is an acronym of Dutch and English words: Klein (small) aantal (number) toetsen (keys) Direct Access System.
The system uses 12 keys (an other number is possible), and allows for direct access of the 26 letters. Each key contains 3 of the 26 characters. Thus, pressing a key will activate three characters at once. Based on statistical tables and the previous three characters, the system predicts the intended character. A prototype of this system is emulated on a PC. The hardware is based on a touch-tone telephone keypad (1, 2). The figure below shows a keypad with the Dutch layout: three characters are assigned to one key and the asterisk-, operator- and number sign key have to be used to disambiguate the characters.



Thus, pressing key 5 and the asterisk key results in the selection of "m". In this ongoing project, software is designed to execute the disambiguation automatically.
The algorithm is based on quadgraph tables and produces the correct character in 90% of all selections at this moment (4). The character, which is selected by the computer is put in the first position of a three character screen window. If this character happens to be wrong, the typist can use the asterisk key to make a correction. The second most probable character will appear in first position. This can be repeated another time if neccessary. The key with the number sign can be used to delete the last character typed in case of a user error. On the average, for each character selected, 1.12 keystroke is needed (the 0.12 extra is needed for correction of the 10% errors). Other strategies, not yet implemented, are available to

diminish the error percentage. The lower row of keys is used for correction and other functions. Many applications based on this system can be foreseen:

- As mentioned above, in a deaf-telephone situation a text telephone can be combined with the new software module.
- With a scanning system, a 3x3 matrix is faster than the usual 6x6 or larger matrices.
- A twelve position eye gaze system allows for affordable and reliable hardware.

It is planned to investigate some of these possibilities.

RESULTS

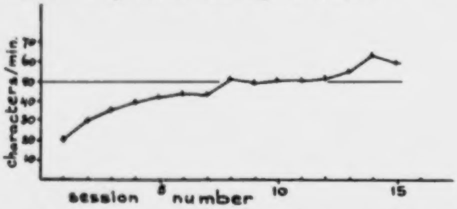
The evaluation of communication systems in the laboratory is difficult to set up. The following parameters influence the outcome of the experiments.

- Type of communication that has to be performed.
- The potential users: maximal motoric output, language development and cognition.
- Environment of the communication.
- Learning situation; duration of learning.

An experimental set-up was designed which reflects the use of a system for production of normal text. A direct interaction situation will differ because of the different use of language during discourse. The design allows comparisons to be made between laboratory situations at other places, with other systems and at other dates. Six subjects were trained to use the input system to be evaluated.

Within five weeks, 15 training and measurement sessions were organized. The text to be entered in the system consisted of different samples of equal length, linguistic properties and had the same type of subject and writing style. A detailed description of this setup will be reported elsewhere.

The results of the training and measurement sessions is given in the figure below.



At the end of the learning curve it appears that with this system a speed of 60 characters per minute is obtained. This is a low speed if it is compared with, for example, the PAL-system from Dundee (5). The PAL-system produces 100 characters/minute under the same conditions. However, it is a rather high speed compared to that of single key scan systems.

CONCLUSION AND DISCUSSION

The results of Katdas are promising when compared with known systems. Of course, Katdas is not as fast as PAL, but this is due to the fact that PAL has a full keyboard available and uses linguistic prediction for automatic word completion. It is expected that higher speeds can be obtained by Katdas if word completion techniques are added and if the feedback situation is improved. At the moment, the typist has to watch the output carefully and correct it due to the existing decoding errors. A new decoding principle is now being developed which requires less feedback and thus allows for higher speed and less attentional load on the user.

ACKNOWLEDGEMENT

The research is carried out in cooperation with the Micro Computer Centre, Dundee (UK), the Reh. Eng. Res. Dept., Dupont Institute, Wilmington (USA) and the Dept. of Computer Linguistics Univ. of Nijmegen (NL). Funding is provided by the Innovation Fund of Aids for the Handicapped, Maarsen (NL) and by he Phelps foundation for spastics, Bussum (NL).

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33.2

A TEXT ENTRY SYSTEM BASED ON FREQUENT LETTER SEQUENCES.

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ABSTRACT

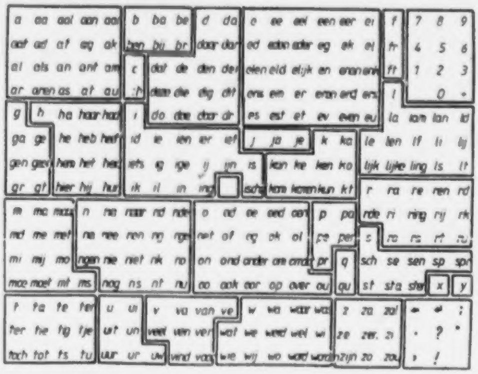
An approach to efficient communication systems for non-vocal, physically disabled people, can be directed at creating the possibility of entering text by means of chunks of words or whole words with one keystroke. The WRITE-system, developed in Boston at Tufts University, is based on this principle(1). This paper describes the conversion of the WRITE-system into a Dutch version which connects to a PC and is called the Combibord. Results of laboratory experiments with this system will be discussed. The results include speed, data and a learning curve.

INTRODUCTION.

The use of computers for the non-vocal physically disabled shows two important areas of application. First, the computer can be used to design a communication aid. Second, the computer can be used as communication aid, or as a simulation of a dedicated application in a phase. A communication aid has linguistic input which is mostly characters, words and complete sentences. An important feature of these systems is how they try to use redundancy in language. In normal conversation it is very helpful to have some level of redundancy in the message. In case of non-vocal and often motor impaired people a bottleneck in the communication process is the speed of entry. Entry of communication elements has to be based on the individuals motoric and linguistic capacity. For this reason it is necessary to have a large variety of entry systems available. A system which exploits redundancy is the WRITE-system which has been developed in Boston(1). This system is based on statistical properties of an orthographically spelled language and must therefore be redesigned for other languages. The next paragraphs decribe the board transformed into Dutch. The Dutch system is called the Combibord.

DESCRIPTION OF THE BOARDS.

The WRITE-board has been designed in four different sizes: with 100, 200, 300 and 400 different entries. Each entry is a letter or a frequent sequence of letters.
The arrangement of (sequences of) letters may vary due to individual preferences. Spelling English by pointing at the board with only the 26 letters of the alphabet requires about 4 pointings/word. The WRITE-300 requires 1.6 pointings per word. The characters and sequences are grouped in alphabetical clusters. The present prototype of the Dutch Combibord has a size of 300 entries. The board contains 252 grapheme sequences, the alphabet, the numbers, punctuation symbols, backspace and return(2). The following figure shows the present Combibord.



This configuration is put on an overlay for the Keyport-300 touch sensitive panel and is connected to a personal computer.

In general, a communication aid consists of an input control (the switches or joysticks etc.), a filter (a direct access, scanning, or combined strategy), an input enhancement strategy (expanding selected codes or word parts to complete words or sentences), an output preparation and an output generation phase.
The original WRITE was intended only as a pointing board and the last phases were the perception and guessing of the listener (enhancement strategy) and the listeners mental activity of concatenating the elements (output preparation). The present Combibord is connected to a PC. It is planned to interface the system to the PAL prediction system from Dundee(3) which requires reconsidering the design concept of this combination because of the different starting-points of the separate systems.

REDESIGN PROBLEMS AND CONSIDERATIONS.

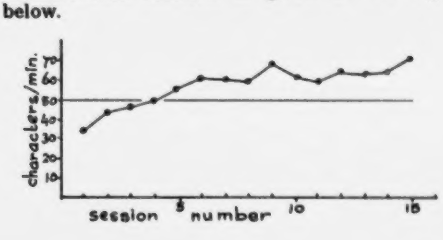
The redesign of WRITE into Combibord concerned the following issues.
The basis for the statistical analyses is a corpus of text. A decision had to be made about which corpus to select: a corpus of

written language, a corpus of transcribed spoken Dutch or a corpus of transcribed spoken Flemish Dutch. It appeared that the resulting lists of 250 most frequent grapheme sequences differed significantly. A one by one comparison between the lists revealed that only a 66 percent of the words appeared in both lists. The differences are probably due to differences in standard spoken Dutch, Flemish spoken Dutch and written Dutch; but also the rather small size of the spoken corpus might have caused the differences (the spoken corpora contained slighty more than 100.000 words). The decision was made to use the total corpus of standard Dutch.

Another special item on the Combibord is the appearance of well known, but not very frequent combinations of characters; i.e. qu, ch, au and ou. These are seen in Dutch as a unity. As mentioned above, the combination of the Combibord with other systems like PAL constitutes a different design problem. The usual WRITE and the Combibord alone have to produce the whole text. In case of a wordprocessor program or a predictive program like PAL, the entry system, the Combibord, is only used to start the predictions. In this case it might be better to provide the Combibord with mainly word initial sequences. Finally, the Dutch language uses concatenation of words to create new words (German is even better known for this pecularity). This creates the problem of ambiguity in case of a word ending. It must be decided whether to attach a space automatically or not: the word may be finished or not.

RESULTS.

An evaluation of the Combibord was carried out in the laboratory with a standardized set-up for experimentation. The experimental set-up included training and measuring performance during 15 sessions in 5 weeks. Six non-handicapped subjects were used. The measurements involved copying of prepared text samples. The samples were chosen to have equal length and linguistic properties and dealt with the same type of subject. The output of the board was directed to a wordprocessing program, inter-key-intervals were measured and errors were recorded. The results of the measurement sessions is given in the figure below.



It can be seen from this figure that the learning process appears to have ended during the experiments. This had not been expected, because of the large number of different entries which had to be used. It has been reported that the ergonomical aspects of the touch board itself were not optimal. An easier to activate board with distinct and larger keys might improve speed and ease of operation. Nevertheless, the results are quite acceptable although no prediction or expansion techniques were used.

FINAL REMARKS.

The main problems of a Combibord seem to be the large number of cells, which creates a search problem, and the trade-off between size of the panel (which should be as small as possible) and the size of the cells (which should be as large as possible).

The last problem could be handled by designing an appropriate scan system or putting several wordparts on a single key combined with a decoding technique described elsewhere(4).

Finally, the proper use of special input systems depends only on the requirements and ability of the potential users. Until now, no systematic research has been carried out to fill in this gap in our knowledge.

AKNOWLEDGEMENT.

The research was carried out in cooperation with the Micro Computer Centre, Dundee and the Reh. Eng. Dept. of the Dupont Inst., Wilmington. Funding was provided by the Innovation Fund for aids for the Handicapped, Maarssen (NL) and The Phelps Foundation for Spastics, Bussum (NL).

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33.3

WORD COMPANSION: ALLOWING DYNAMIC WORD ABBREVIATIONS

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Abstract

In this paper we describe a system, which we call word compansion, which is designed to enhance the communication rate of a disabled individual who is using a spelling technique to enter his/her desired message. The system saves the user key strokes by allowing the input of individual words to be in abbreviated form. This work is novel in that the abbreviations are not decided in advance, but are dynamically created by the user at input time.

Introduction

Up until now, *abbreviation expansion* has been the method used by systems which allow abbreviated word input from the user. Abbreviation expansion is a technique that allows the user the ability to input to the system a sequence of letters (that do not correspond to a word) as an abbreviation for a word or phrase [4]. Letter sequences are typically delimited with spaces. The system performs a lookup to a table containing the abbreviation and its true word or phrase representation (expansion). If an expansion is returned, it is substituted for the abbreviation in the text stream.

Word compansion is similar to abbreviation expansion in function but has important differences. The biggest difference is seen from the point of view of the user of the system. In abbreviation expansion the compressed sequences must be decided in advance and memorized by the user. While this constraint allows the system to work very fast, it places an unreasonable burden on the user. In word compansion this burden is lifted. Using word compansion the user is permitted to input novel compressions for words. The system, using its knowledge of the language, knowledge of the likelyhood of certain sequences of letters to be part of an English word, and knowledge of how a human is most likely to form a compression of a word, returns a set of one or more possible interpretations for the user's input.

Background

In doing word compansion, the major task is to come up with the correct expansion of the user's dynamically compressed word in a reasonable amount of time. Our work has borrowed from work in word recognition for heuristics to choose the correct expansion, and from abbreviation systems for insight into the kinds of abbreviations we might expect.

Word Recognition

A great deal of psychological literature has been devoted the cognitive processes that occur during the activity of reading. One major area of study is word recognition. Most models of word recognition are based on a number of cooperative processes that transform visual information into a semantically meaningful collection of words. Out of this area of study, we have found several relevant concepts.

Orthographic - Venesky and Massaro [5] present a two component model that describes the role of orthographic information in word recognition. *Statistical redundancy* processes are based on the frequency of occurrence of letter sequences. *Rule governed regularity* is based on phonological constraints that exist in spoken language.

Lexical Access - Burani et. al. [1] discuss lexical access from the point of view of morphological structure. One of the major components of lexical access is word frequency; a higher word frequency results in quicker access. This frequency has two major components: a measure of frequency over the individual's total experience and a local frequency representative of recent experience.

Context cues - The effects of context on word recognition are widely disputed [3] although there is some agreement on what the actual mechanism should be. Previous words set up an expectancy that helps in limiting the domain of possible words.

Abbreviation Systems

Many abbreviation techniques have been developed for use by secretaries for real time transcription of spoken language. Speedwriting is an example of such a system which is in current use [2]. It combines some simple shorthand principles with abbreviation techniques. An example rule is vowel deletion. You can delete all vowels except for those that begin the word.

Model

A model has been developed for word compansion that incorporates several of the concepts previously discussed. The model enables the user to use two different kinds of abbreviation techniques. Upon receiving a letter sequence from the user, the system first checks to see if that sequence is a word in the dictionary or is an element in a user programmed abbreviation expansion table. If it is not, then the system checks to see if the input string is a prefix of a word in the system's dictionary (currently nearly 6000 words). This step enables the user to use an abbreviation such as "prob" for the word "problem".

If both of the above steps fail to identify the word, then it is assumed that the input sequence is a dynamically created abbreviation. Our strategy in this case is based on three assumptions (1) the initial letter in the sequence is rarely deleted (with the exception of an e preceding an x as in "extra"), (2) the most commonly deleted elements will be vowels and double consonants, and (3) each letter in the abbreviation string will occur in the target word in the order in which it occurs in the abbreviation.

Our strategy works in two directions at the same time: from the input abbreviation to potential words in the dictionary, and from potential words in the dictionary to the abbreviation. This enables us to constrain our search from two directions: we do not consider expansions of the input sequence which cannot correspond to English words, nor do we consider English words which do not have crucial resemblances to the input sequence.

Of course, in order for this enterprise to be successful, (a small list of) potential dictionary word candidates must be identified rather quickly. Since retrieving words with a particular prefix can be done quickly, we have chosen this as our retrieval method. Given the user's input sequence we must identify possible prefixes for the target word. Based on our above assumptions, we go to the first position in the input sequence from which letters could have been deleted (between the first two given letters) and create a list of potential prefixes for the target word by inserting all combinations of 0, 1, 2, or 3 vowel strings which occur in the words of the language. We then retrieve from the dictionary all words that have any one of the identified prefixes.

Each member of this list is compared with the original input string and all members are returned which contain all letters in the original input sequence in the order in which they occur in that sequence. If exactly one word results, this word replaces the input sequence in the user's input string. If more than one possibility results, then the system opens a special window and scans through the list of possibilities ordered by their frequency of occurrence in the language. The user chooses the desired word by hitting any key.

Discussion

The generality of the method developed allows the user to be most terse in the dynamically created abbreviation. On the other hand, because the system places so few constraints on the user, the system may often be unable to narrow down the choice of words to exactly one. This can be alleviated by customizing the system to the abbreviation strategies of individual users and/or by enhancing the system with information about the syntactic and semantic context of the compressed sequence. Strategy customization may be particularly useful in the second stage of processing (i.e., in matching the input sequence against potential dictionary words). This match currently allows insertion of any number of arbitrary letters. It may be useful to place limits on the number of letters deleted and their type (e.g., vowels). The addition of syntactic and semantic contextual constraints is the subject of continuing research in this area.

Acknowledgements

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33.4

ACCESS: A lexical access program

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Abstract

A program is described which predicts words from partial information. Information may be the first letter of the word, any other letter(s) in it, its part of speech and/or the number of syllables in the word. Predicted words or word and sentence output may be heard via synthetic speech. Examples are given of use with a small lexicon for training names of vegetables.

Introduction

ACCESS is a program designed to aid in message construction which does not presuppose the ability to spell a word. The goal is to use any information that the user has about a word to "access" it. Information supplied by the user prompts suggestions, or predictions; one of these may then be chosen, or a new set of suggestions requested. Each chosen word and each sentence may be heard in synthetic speech. The particular facility of ACCESS to allow alternative input could be helpful both as a training aid for children having difficulty in reading and writing, and for certain persons experiencing disabling effects of aphasia (Hunnicutt, 1987).

The information currently accepted by the program is: first letter, any other letter(s), number of syllables and word class. The program predicts up to five words that agree with the information given. If no information is given and predictions are requested, the five most frequent words are given. In any case, the user may accept one of the predictions, request another set of predictions, commence predicting again with the same information, or with help, type in a new word. Other information which is planned to be accommodated is approximate word length which will be indicated by outlining an area on the screen and stress (accent) which may be included in the same way. Semantic information for a subclass of words is also being made available.

The algorithm and lexicons

ACCESS consists of an algorithm and several lexicons. The two main lexicons contain up to 5,000 words. One of them is indexed by first letter, and within each letter group, by word frequency. This lexicon is searched whenever the first letter of a word is part of the given information. It is called the Main Lexicon. The other main lexicon , called the Frequency Lexicon, contains exactly the same words, but is indexed wholly by frequency. This lexicon is searched whenever the first letter of the desired word is not included in the information given by the user.

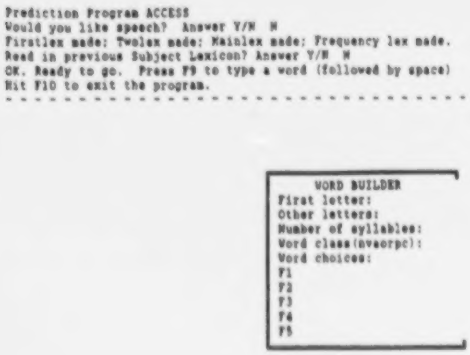
A third lexicon can be initially empty or can be a file of up to 500 subject- or situation-specific words. This lexicon is called the Subject Lexicon. Data is accumulated in it as the program is used. This lexicon may be used to update the main (alpha-sorted) lexicon, and can be saved for later use.

Another lexicon, the Word-Pair Lexicon, contains common word pairs, so that the second word of a word pair may be automatically predicted when the first word in the word pair has been entered. Up to five such second halves may be specified for each first word entry. A small lexicon containing the five most frequent words for each letter is also included. It is called the First Lexicon.

Examples of training with a small lexicon

It is also possible for a teacher or therapist to construct small lexicons for training. These lexicons might be constructed to be used with a set of pictures, for example. One such lexicon which has been constructed (in Swedish) is a vegetable lexicon. Following are several examples using this lexicon (translated and made appropriate for English):

In Figure 1, a copy of the computer screen is shown at the time use commences. The user is first asked if speech output is desired. This questions may be answered affirmatively if the computer being used (an IBM-compatible type) contains an Infovox speech synthesis card. The permanent lexicons are then read in. The user may then choose whether to use one of his/her subject- or situation-specific lexicons, a Subject Lexicon. After a few short operating instructions are given, a Word Builder is printed in the lower right-hand corner of the screen. In this working area, the user types in information to the lexical access program and receives up to five words as possible matches. When words are chosen using the function key designated to the left of each prediction, they are written in the message area below the instructions and above the Word Builder. As the message accumulates, the text moves up on the screen while the Word Builder maintains its position in the lower right corner of the screen. In the following examples, all new information and predictions are given in the Word Builder, so the remainder of the screen will be ignored.

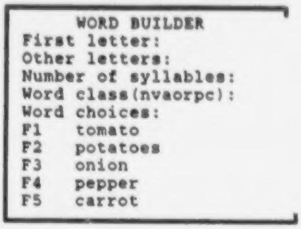


```
Prediction Program ACCESS
Would you like speech?  Answer Y/N  N
Firstlex made: Twolex made: Mainlex made: Frequency lex made.
Read in previous Subject Lexicon? Answer Y/N  N
OK. Ready to go.  Press F9 to type a word (followed by space)
Hit F10 to exit the program.
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -

                              WORD BUILDER
                         First letter:
                         Other letters:
                         Number of syllables:
                         Word class(nvaorpc):
                         Word choices:
                         F1
                         F2
                         F3
                         F4
                         F5
```

Figure 1. Initial screen configuration

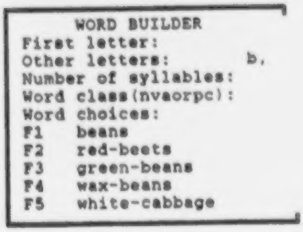
If the user wants to see (and, optionally, to hear) the most frequent words, he/she may just type a space. In the case of the vegetable lexicon, the words "tomato," "potatoes," "onion," "pepper" and "carrot" appear on the screen as seen in Figure 2.



```
      WORD BUILDER
First letter:
Other letters:
Number of syllables:
Word class(nvaorpc):
Word choices:
F1    tomato
F2    potatoes
F3    onion
F4    pepper
F5    carrot
```

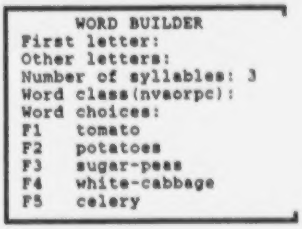
Figure 2. Typing "space" to get frequent words

If the letter "b" is chosen as a non-first letter, Figure 3 shows the resulting suggested words: "beans," "red-beets," "green-beans," "wax-beans," and "white-cabbage." (Note: the hyphenated words are single words in Swedish.) Let us say that the user picks "beans" and goes on to ask for vegetables with three syllables. The words "tomato," "potatoes," "sugar-peas," "white-cabbage" and "celery" are then printed as shown in Figure 4. If the user then decides that it was 2 syllables that was desired and not 3, the "2" may simply be overwritten with a "3" and the suggestions "onion," "pepper," "carrot," "carrots" and "mushroom" are given. If the desired word is not in this list, typing "space" will give a further list of suggestions. Typing "carriage return" would begin the search again with the same information.



```
      WORD BUILDER
First letter:
Other letters:        b,
Number of syllables:
Word class(nvaorpc):
Word choices:
F1    beans
F2    red-beets
F3    green-beans
F4    wax-beans
F5    white-cabbage
```

Figure 3. Typing "b" as an other letter



```
      WORD BUILDER
First letter:
Other letters:
Number of syllables: 3
Word class(nvaorpc):
Word choices:
F1    tomato
F2    potatoes
F3    sugar-peas
F4    white-cabbage
F5    celery
```

Figure 4. Typing "3" as number of syllables

Further development

The ACCESS program is now being run by several speech pathologists in Sweden. Their experience will hopefully provide needed information about how to improve the program and make it more useful to those it is intended to serve.

Acknowledgement

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33.5

A COMPARISON OF WORDS STRATEGY AND TRADITIONAL ORTHOGRAPHY

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ABSTRACT

Words Strategy is a relatively new software program designed for use with the Prentke Romich Touchtalker. It is generally targeted for use by speech-impaired or nonspeaking adults who have, however, intact language skills and at least a rudimentary knowledge of grammar. This study was designed to develop a learning curve for Words Strategy, and to compare TouchTalker communication speed using Words Strategy with traditional orthography. An additional goal was to determine if, as Light (3) has suggested, increasing the number of associations per icon also increases the number of icon confusions. Results indicated that after approximately 15 hours of training, sentence input speed for Words Strategy surpassed that of traditional orthography. Furthermore, the data did not support Light's contention. Results also indicated some recommended changes to both the software and the traditional Minspeak overlay.

INTRODUCTION

Communication speed has often been cited as one of the major problems facing the field of augmentative and alternative communication (1). Early augmentative communication systems were inflexible, limited in vocabulary, and allowed the user to communicate only at a maddeningly slow pace. The Prentke Romich Touchtalker with Minspeak greatly improved upon this situation. However, sentence-based Minspeak still prohibits the communicator from saying exactly what he/she wants to say. Words Strategy was designed to provide the communicator with more flexibility by allowing access to the full range of linguistic possibilities, as long as the communicator has intact language skills and some knowledge of grammar.

Since Words Strategy is new, there is little research assessing, in detail, its potential for increasing communication speed over other methods and devices. The current research was designed to provide baseline data comparing the upper limits of communication speed of the Touchtalker, using both traditional orthography and Words Strategy.

Another purpose of the present study was to address a question raised by Janice Light (4), who has suggested that as the number of associations attached to an icon increases, the memory load on the communicator may serve to increase icon confusions.

METHOD

Subjects. Sixteen college students at Ohio University served as subjects.

Apparatus. The Prentke Romich Touchtalker was used in this study, and fitted with a typewriter overlay for the traditional orthography (TO) group, and a "traditional" Minspeak overlay for the Words Strategy (WS) group. Two-hundred fifty words, taken from the most frequently used vocabulary words as denoted by Howes (3) were chosen, and divided into six sets for Words Strategy training (one set for each week of training). Six tests consisting of 20 sentences each, utilizing a given week's vocabulary along with vocabulary from the previous week(s) were also constructed. These test sentences were different from those used for the training/practice sessions.

A traditional typing test was administered to each subject at the beginning of the study to determine typing speed. A digital stopwatch was used to measure timing of sentence inputs during the tests.

Procedure. Subjects in the TO group were given a one hour introduction to the Touchtalker during the first week of the study. They then received one hour of typing practice per week on the Touchtalker. Practice sessions consisted of typing sentences constructed using words in each week's vocabulary, as well as vocabulary from the previous week(s). At the end of each week, subjects took the sentence test for that week, and typing speeds were measured. Subjects in the TO group continued this procedure for six weeks, for a total of six tests, and 7 hours of experience with the Touchtalker.

Subjects in the WS group were given two 3 1/2 hour introductory sessions describing, in detail, the Words Strategy program. Thereafter, for the next six weeks, they learned one vocabulary set each week, along with the "rationale" (i. e., suggested mnemonic association in Words Strategy between a word and its icon) for each word and it various forms. The testing procedure was the same as for the TO subjects, except that there were three hours of training/practice prior to each test. Thus, Words Strategy subjects received 25 hours of experience with the TouchTalker. The difference between the two groups was necessitated by the fact that the first group had nothing to do but type, and could not be expected to participate for 25 hours.

Design. The experimental design was a 2x2 x2x6 mixed design. The between-subjects independent variables were method (TO and WS) typing classification (occasional typist vs. typist), and input mode (one-fingered vs. multifingered). The within-subject variable was sentence test (1-6). The dependent variable was the average sentence input speed. Data were analyzed using analysis of variance (ANOVA).

RESULTS

Results indicated a significant difference between TO and WS subjects over the six tests. TO subjects outperformed WS subjects for the first 2 tests. The two groups showed approximately equivalent performance on the third test. Thereafter, performance was reversed; the WS subjects input sentences faster than TO subjects for tests 4, 5 and 6. By the sixth test the WS rate was over 32 wpm, as compared to the TO rate of 25 wpm, which was asymptotic by test 2.

While TOs asymptoted quickly, WS subjects did not reach performance asymptote by the end of the study. Analysis of the learning curve data indicates that performance using Words Strategy would asymptote at 42.4 words per minute.

Table 1 indicates that, if number of usages required for an icon is taken into consideration, there is no evidence that increasing the number of icon associations increases the number of icon confusion errors, at least not in the range of 1-7 associations. Thus, the data do not appear to provide support for Light's (1988) hypothesis.

Other results indicated that WS subjects had far more grammar label confusion errors than icon confusions errors, and the former tended to occur within, rather than between, grammar label groups. Certain errors were also a function of the icon placement and/or pictorial features.

Table 1

No. of Assoc.	No. of Icons	No. of Errors	No. of Usages	% Errors
2	5	15	318	4.72
3	2	8	193	4.15
4	3	10	397	2.50
5	6 ***			
6	2	17	306	5.55
7	1	8	135	5.93

*** although there were six icons with five associations, there were no confusion errors observed in this category.

Further work is currently under way to compare traditional orthography and Words Strategy in a conversational dialogue task, to see if the results from this sentence input task generalize to the application situation.

The authors gratefully acknowledge support of this research from the Prentke Romich Company and Semantic Compaction Systems.

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34.1

MECHANICAL FEEDING AID INCORPORATING VIBRATION ISOLATION OF HAND TREMOR

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ABSTRACT

A feeding mechanism has been developed which transforms steady, vertical hand motion into the scooping motion of a spoon. The mechanism incorporates vibration isolation through a spring-damper system, to attenuate the transmission of low frequency (2-8Hz) hand tremor to the spoon. Reductions in tremor amplitude at the spoon of between 5 and 12% have been achieved.

The prototype has been tested by four ataxic patients. The level of vibration isolation and the ability to pick up food were adequate but some patients had difficulty holding the handles.

INTRODUCTION

Severe hand tremor can be a symptom of Parkinson's disease, multiple sclerosis, Huntingdon's chorea and ataxic spasticity. The frequency of the tremor lies within the range 2-8 Hz [1] but the detailed frequency/amplitude characteristics of the tremor differ slightly according to the disease. Parkinson's tremor frequency is between 4-8 Hz and has a lower amplitude than the 2-4 Hz MS tremor.

A large and varied number of feeding aids have been developed for the disabled and infirm but very few have dealt directly with the problem of hand tremor. Only one such device is currently on the market and that uses pure damping as a means of attenuation. The potential of vibration isolation appears to have been ignored.

BACKGROUND

The aim of vibration isolation is to reduce the amplitude of oscillations as they are transmitted through a mechanism. The standard method is to interpose a spring between the exciting vibration, in this case the hand, and the mechanism carrying the spoon. By choosing a suitable spring stiffness with respect to the inertia of the mechanism, the spring can be made to 'absorb' the oscillations and instead transmit a steady uni-directional force. A certain amount of damping is necessary to prevent resonance if the excitation frequency approaches the natural frequency of the mechanism.

An earlier mechanism designed by the author [1] used a sprung handle to control a four bar linkage. Although it worked well as an isolator, the lack of damping meant there was little resistance to an applied force and ataxic patients found it impossible to control.

DESIGN DESCRIPTION

Most examples of vibration isolation can be represented by figure 1a. The damper acts as a pathway between the support and the mass, thereby increasing the transmission ratio. However, if the damper can be 'earthed' as in figure 1b, the damping force resists the motion of the mass and an increase in damping produces a decrease in the transmission ratio. This was the principle used in the design.

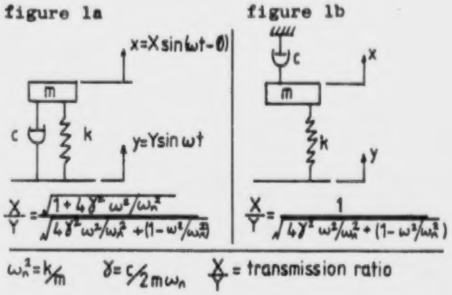


figure 1a

figure 1b

$$\frac{X}{Y}=\frac{\sqrt{1+4\gamma^2\omega^2/\omega_n^2}}{\sqrt{4\gamma^2\omega^2/\omega_n^2+(1-\omega^2/\omega_n^2)}}$$

$$\frac{X}{Y}=\frac{1}{\sqrt{4\gamma^2\omega^2/\omega_n^2+(1-\omega^2/\omega_n^2)}}$$

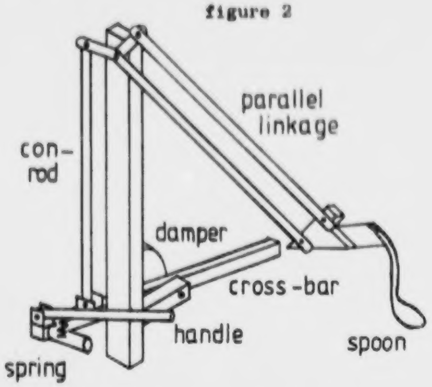
$\omega_n^2=k/m$ $\gamma=c/2m\omega_n$ $\frac{X}{Y}$ = transmission ratio

Referring to figures 2 and 3, the feeder consists of a parallel linkage mechanism driven by a pivotted cross-bar, via a rigid connecting rod. To raise and lower the spoon, the user presses down on one of the two sprung handles, causing the cross-bar to rotate. The motion of the cross-bar is controlled by a rotary viscous damper which is bolted to the base board.

Spoon motion and picking up food

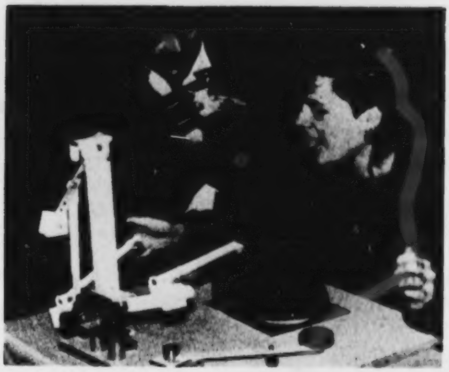
A standard spoon is used for liquids and a dished fork for solids. The spoon is bolted to a hinged plate on the end of the parallel linkage. When the spoon contacts the plate on the downstroke it rotates about the hinge, dipping one edge into the liquid. This freedom to rotate also allows the spoon to slide across the surface of

figure 2



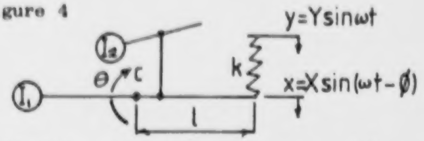
the plate for the last 4" of travel. On the upstroke, the weight of the spoon causes it to drop back to the horizontal as it leaves the plate, completing the scooping action. The parallel linkage then maintains the spoon in the horizontal until it reaches the mouth. For solids, the teeth of the fork dig into the food on the upstroke thereby dragging the fork in deeper. The feeder can also be rotated about its vertical axis, so that the spoon can be raked across the plate.

figure 3



Vibration analysis
Figure 4 shows a schematic representation of the feeder. Weights were added to each end of the cross-bar and to the linkage, so as to raise the moment of inertia and to provide counterbalancing of the spoon. Solving the equation of motion gave:
$\omega_n^2 = kl^2/I$ and $\gamma = c/2l\sqrt{Ik}$
The value of the added weights gave I=0.05 kg m^2 and a spring stiffness of 340 N/m was chosen to produce a natural frequency (ω_n) of 2 Hz. The damper was adjusted to provide critical damping, as this is the value for optimum isolation. The theoretical transmission ratio was then calculated from the equation in fig.1b. for different excitation frequencies.

figure 4



Equation of motion: $x = l\theta$

$$I\ddot{x} + c\dot{x} + kl^2x = kl^2y$$

RESULTS

Taking into account the geometry of the cross-bar assembly, an excitation of frequency 3Hz and amplitude 50mm should have caused the con-rod to vibrate with amplitude 2.5mm, i.e. a transmission ratio of 0.05 (the T.R. due to the spring alone was 0.3). This should have then been amplified by the geometry of the parallel linkage. However, the deliberate sloppiness of its pin joints reduced the amplitude response of the con-rod even further. Observed amplitudes at the spoon were between 5 and 12% of the amplitude of the hand (as measured visually against a graduated scale).

In summary, the vibration isolation of the mechanism was sufficient to enable a hand, vibrating with amplitude 50mm, to raise a spoonful of soup with minimal spillage. Furthermore, the feedback from the damping force and the simple up/down method of operation made the feeder controllable by severely ataxic patients. However, the handles were difficult to grip and there was a great deal of user antipathy to the appearance of the device.

CONCLUSIONS

It is possible to use vibration isolation in the design of feeding mechanisms for patients with severe hand tremor. Viscous damping can be included to provide tactile feedback to aid control, at the same time increasing the degree of isolation at all frequency ratios.

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34.2

DEVELOPMENT OF A WHOLE-ARM ORTHOSIS FOR TREMOR SUPPRESSION

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ABSTRACT

Abnormal intention tremor is an involuntary rhythmic oscillation superimposed on any purposeful motion . It has been shown that significant tremor reduction can be achieved by applying mechanical loads to the affected limb or body segment. We have developed the first version of a whole-arm orthosis for applying viscous damping . The primary goal of a CEDO (controlled energy dissipating orthosis) for whole-arm motion is to achieve considerable tremor reduction without limiting the range of activities of daily activities the patient can perform . We have dealt with the design issues , technical and user-oriented , such as kinematics , safety ,controls and dynamics , in developing the present design . Experimental evaluation of the orthosis effectiveness and possibilities for future work have been planned .

INTRODUCTION

Abnormal intention tremor is an involuntary rhythmic oscillation superimposed on purposeful movement . The disability arises from the fact that in many cases the amplitude of the involuntary movement is large enough to degrade or obscure voluntary motion attempted by the patient. The number of patients disabled by abnormal intention tremor in the U.S. is about 750,000. Drug therapies and surgery have been attempted with limited effectiveness and considerable risk for the patient.

It has been experimentally demonstrated that significant tremor reduction can be achieved by the application of viscous damping to the limb or body segment [1]. Tremor patients , on the average , show acceptable muscular strength and good volitional control in the affected body segment , so they would benefit from a technique that suppresses tremor while allowing voluntary motion. This approach has been used for the design of a wheelchair joystick for tremor patients [2], and it is central to the design of a six-degree-of-freedom orthosis for tremor management of whole-arm motion presently under development at this laboratory (MIT Newman Laboratory for Biomechanics and Human Rehabilitation).

GOALS

The main objective of this project is the development of CEDO I , a prototype functional orthosis for tremor suppression of whole-arm motion, which is wheelchair based. The first goal is that orthosis must be capable of applying sufficient damping to achieve considerable tremor suppression in the upper limb. The second is that the orthosis must allow the patient to perform a number of activities of daily living (ADL) with a minimum of interference. The degree to which this is achieved is called the "functional compatibility" of the orthosis and patient. The last goal is making the orthosis acceptable for the patient in terms of safety and cosmetic appeal.

DESIGN ISSUES

The first design issue is the actuator selection, i.e. the type and characteristics. Because the orthosis is coupled to the patient , safety considerations dictate that only energy absorbing actuators be used (brakes) as opposed to positive energy actuators which are capable of moving the patient (i.e. motors). The amount of damping required for the desired reduction of the worst-case tremor is unknown due to an incomplete understanding of tremor mechanisms . Therefore, a conservative estimate was used for selecting the actuators . The actual load determination will be done by experimental evaluation .

Another design issue is the selection of a kinematic configuration which affects the "functional compatibility" of the orthosis . To determine the functionality of a given design , real-sized kinematic models can be evaluated by able-bodied subjects performing activities of daily living . CEDO I has the same configuration of the Ball Bearing Feeder Orthosis [3] which has a high " functional compatibility" . The kinematics also affect the ability of the orthosis to produce an endpoint damping force parallel to the endpoint velocity. The importance of force/velocity colinearity is unknown, trying to achieve it increases the design complexity . In the design of CEDO I, simplicity had priority over force/velocity colinearity.

The last design issue is the mechanical properties of the orthosis and their effect on the orthosis dynamics. The amount of damping that can be applied to the orthosis before vibration starts and the frequency at which this occurs are determined by the stiffness-to-mass ratio of the orthosis. The CEDO I uses mostly aluminum and large cross-section areas to achieve a high stiffness-to-mass ratio. A high stiffness is also desired in the directions in which the orthosis will rigidly restrain the patient's motions.

CEDO I

The CEDO I is a wheelchair-based three-degree-of-freedom orthosis that allows the patient to move the midpoint of the forearm in a horizontal plane and tilt the forearm out of this horizontal plane. It applies the

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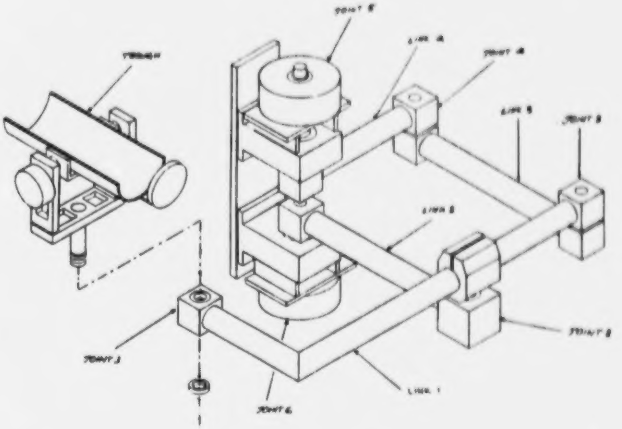

Figure 1 - Controlled Energy Dissipating Orthosis I

damping force at the endpoint using the particle brakes that are mounted at the base which apply a torque proportional to input current. The CEDO I is controlled by a computer which measures the joints' velocities and produces a proportional damping force by modulating the currents of the brakes at the joints. The five-bar linkage is used to place the brakes at the base instead of some midpoint of the orthosis, i.e. the elbow, reducing the effective inertia that the patient feels at the endpoint. The maximum effective endpoint mass is 2 lbs. The lowest resonance frequency of the orthosis is 10.5 hz and the maximum viscous load that can be applied before vibration starts is twice the maximum load of the brakes actually used in CEDO I. The maximum endpoint deflection is 0.15 in. under a 50 lb. load at the endpoint.

EXPERIMENTS

The experimental evaluation consists of two phases. The first phase requires the patient to track a target on a computer screen while using the CEDO I, to measure the patient's performance. The second phase requires the patient to use the CEDO I for activities of daily. These experiments will provide information of the necessary damping force levels for effective tremor reduction, the importance of force/velocity colinearity, and the patient's acceptance of the orthosis.

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34.3

FABRICATION TECHNIQUES FOR DIRECTLY IMPLANTABLE MICROELECTRONIC NEURAL INTERFACES

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ABSTRACT

Fabrication techniques for directly implantable microelectronic neural interfaces are under development at Stanford University and the Palo Alto Veterans Administration Medical Center. This paper describes the present status of this work and its relation to the overall goal of the project which is to develop a chronically implantable neural interface to couple external electronic and mechanical devices to the human nervous system.

INTRODUCTION

This project involves the development of two-dimensional microelectrode arrays which will be used as direct interfaces to peripheral nerves [1], [2]. These devices will provide a link between the human nervous system and external devices such as motor/sensory prostheses. Figure 1 is an artist's conception of a directly interfaced hand prosthesis utilizing such a neural interface.

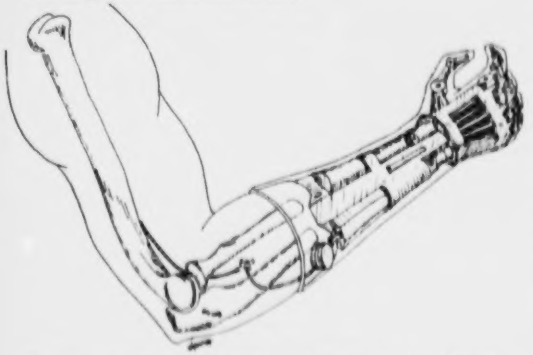

Figure 1, Artist's conception of a directly interfaced hand prosthesis.

The devices currently under development consist of silicon integrated circuits through which via holes have been etched. These devices are held between the ends of severed peripheral nerves, with the via holes providing a path through the device for regenerating axons. Addressable electrodes adjacent to the via holes constitute the actual interface between the microelectronics and the neural tissue. The axons are spatially fixed by the via holes with respect to the microelectrodes.

BACKGROUND

In 1973, Llinás, et al. [3], published a remarkable paper describing how a silicon-based microelectronic neural interface might someday be implemented. They proposed utilizing integrated microcircuits to control addressing of individual microelectrodes in a two-dimensional array of via holes (each containing a regenerated peripheral nerve axon). Prior to this, and in the following years, several groups studied regeneration electrodes made from non-semiconductor materials (reviewed in [4]). In 1979, Matsuo, et al. [5] were the first to attempt fabrication of a silicon-based regeneration electrode array with large via holes (200 X 200 μm) with integrated single field effect transistors. These via holes would probably each have contained hundreds of axons. In 1981, Edell [6] was the first to fabricate a functional passive neural interface utilizing large (≈2 X 0.16 mm) slots etched in a silicon substrate. He also developed the basic concepts of the surgical coupler used to hold the severed nerve ends against the interface and proved that chronic recordings could be made with silicon-based devices. Rosen, et al. [4] showed that small groups of regenerating axons could be isolated in 8-12 μm laser-drilled via holes in blank silicon devices. It is the goal of the project described herein to fabricate neural interfaces which establish electrical communication with individual axons in peripheral nerve fascicles and which include microelectronic circuitry to control this information flow.

FABRICATION PROCESS OVERVIEW

The first phase of the project has been the development of the novel microelectronics fabrication processes required to prepare integrated circuits for direct implantation in the human body. We have developed a process which is directly compatible with commercial integrated circuit fabrication technologies in order to reduce the ultimate cost of the neural interfaces and help deliver them to their end-users in an expedient manner. The current process, developed at the Stanford University Center for Integrated Systems, consists of three basic steps:

METALLIZATION: Iridium was selected as the microelectrode metal due to its extremely low dissolution rate and ability to withstand high current densities when used as a stimulating electrode. It is able to form an insoluble and conductive anodic oxide layer which greatly lowers its electrical impedance. This reduction of impedance is of tremendous importance in recording applications as well, since the thermal noise level of a microelectrode is reduced with this parameter. Since iridium is extremely unreactive, conventional metal patterning techniques (which rely on wet chemical or plasma etching to remove unwanted metal) could not be utilized. A *lift-off* iridium patterning process was developed which is illustrated in figure 2 below.

PASSIVATION: Plasma Enhanced Chemical Vapor Deposited (PECVD) silicon nitride was chosen as a passivation layer due to its excellent alkali ion blocking capacity (these ions can destroy MOS transistors). When deposited with this technique, it is able to coat steep sidewalls such as those of the via holes [1]. As well, the PECVD process is carried out at a sufficiently low temperature that it will not damage pre-fabricated microelectronic devices. The deposited silicon nitride layer is opened selectively at microelectrode sites and bond pads using a plasma etch process.

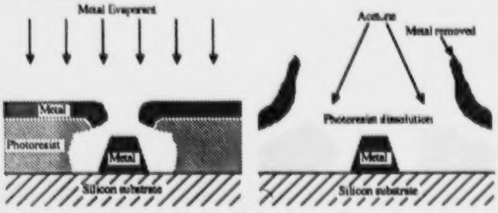

Figure 2: Illustration of lift-off metal deposition.

VIA HOLE PLASMA ETCH PROCESS: A technique for fabricating the via holes for axon regeneration was required which would not damage the silicon surface (the laser drilling process caused irreversible damage). A plasma etch process was developed which meets this requirement and is able to provide the required etch depths (in excess of 100 µm). Silicon devices with via holes etched in this manner were implanted in rats to verify their biocompatibility. After 3 months, individual myelinated axons were observed (by electron microscopy) both within and distal to the via holes. Electrophysiological studies confirmed the viability of the regenerated axons.

PASSIVE ARRAYS

The three basic process steps described above were combined to fabricate the first prototype microelectrode arrays. These arrays were fabricated on oxidized silicon to simulate integration with a commercial MOS process. The resulting devices were thinned by mechanical lapping to the target thickness of 100 µm.

Figure 3 shows a completed passive microelectrode array (one of several designs) mounted in a surgical coupler. Electrical connection pads to the array are visible above the coupler. Several of these assemblies have been implanted in rats and we are currently awaiting axon regeneration to take place before undertaking electrophysiological studies.

ACTIVE ARRAY DESIGN

As described in a prior publication [2], a functional active neural interface array has been designed and fabricated utilizing a commercial CMOS process. While the prototype devices were not intended for implant, they served to verify many of the design principles for the implantable versions. As well, they facilitated the development of several novel testing techniques required for future versions.

CONCLUSIONS

This is a long-term project which is still several years from clinical applicability. Microelectronics fabrication technologies for these devices have been implemented and are being refined. Steady progress is being made toward demonstration of a functional neural interface in animal models.

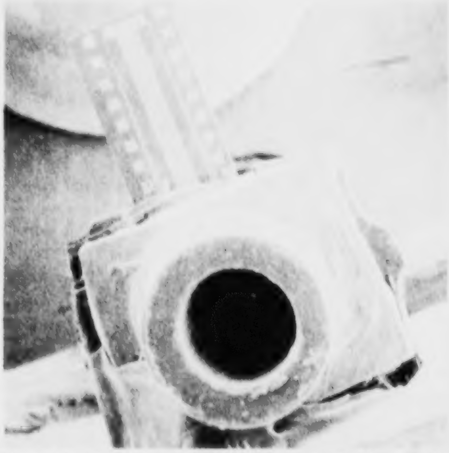

Figure 3: Scanning electron micrograph of a passive neural interface assembly. (magnification = 16.5 X)

AKNOWLEDGEMENTS & SUPPORT

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34.4

COMPOSITE ARTIFICIAL NERVE GRAFTS

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ABSTRACT

This paper summarizes the current state of the art of artificial peripheral nerve grafts (ANGs) and the results of experiments in which various natural and synthetic biomaterials are combined to enhance the regeneration of axons across a gap between proximal and distal nerve ends.

INTRODUCTION

In repair of peripheral nerve injuries, there may be a gap resulting from resection of damaged nerve that is too wide for direct anastomosis; a graft is then necessary. Since autologous nerve is in short supply, a synthetic substitute would be desireable.

The ideal ANG offers a repair technique which requires no donor graft; therefore, no further compromise of other functions is necessary. This method of repair is especially important in the patient who has had previous amputations or spinal cord injuries because very limited or no donor graft is available. Improvement of this technique of nerve repair could lead to faster regeneration and consequently to reduction of denervation muscular atrophy.

BACKGROUND

The rationale for the concept of the tubular ANG derives from evidence that retention of the fascicular sheath promotes axonal regeneration [1]. The basal lamina is preserved in a crushed nerve and acts as a guide tube or mechanical scaffolding through which the axons can grow [1,2]. Also, the guide tube may act as a protective chamber to isolate the regenerating axons from inflammatory and scarring processes [3]. Experiments using autogenous veins as passive conduits found them acceptable but far from being an ideal graft [4, 5]. Pseudosynovial or mesothelial tubes have been reported moderately successful [6-10], as are various resorbable materials [11,12]. Recently, Chiu, *et al.*, reported clinical trials using veins as passive guides alone to bridge 15 mm and longer nerve gaps. Beyond 15 mm, they noted that nerve regeneration arrested and suggested that this phenomenom may be due to the lack of trophic factors or substrates [13].

MacKinnon *et al.* [10] used polyglycolic acid (PGA) tubes to bridge nerve gaps. Although they reported favorable clinical results in digital nerves with shorter gaps, outcome was poor in longer gaps up to 3 cm and in large fascicular nerves (median nerve at the wrist). MacKinnon's group has also experimented with glycolide trimethylene carbonate (GTMC) tubes filled with serum to bridge gaps up to 5 cm. Preliminary trials showed that beyond 3 cm there was only a thin ribbon of tissue which seemed to be functional by motor response to nerve stimulation [14].

Collagen type I and type III have been demonstrated in human femoral nerve [16], with type III predominant within the nerve fascicle. Studies of nerve regeneration suggest that collagen is not only produced by fibroblasts but also by Schwann cells [16,17]. Since fibroblasts are scarce in the endoneurium [18], it was concluded that the Schwann cell is the most probable candidate for synthesis of collagen type III [19]. Our initial experience with collagen-filled ANGs (predominantly type I) demonstrated axonal regeneration, but less so than autografts in the rat model [20].

METHODS

Experiment 1: Since intrafascicular collagen is implicated in regeneration, we conducted a preliminary study to determine the effect of collagen type III on axonal regeneration in tubular ANGs in the rat. Solutions of five different ratios of collagen type I and type III (I:III = 100%:0%, 75%:25%, 50%:50%, 25%:75%, 0%:100%) were injected into PGA or GTMC tubes 1 mm in diameter and 10 mm long. Nerve regeneration across a 5 mm gap was evaluated in a total of fifteen rats by electrophysiology and quantitative histology at 6 to 7 months post-operatively. A longer study is now being completed.

Experiment 2: In another experiment in the monkey, segments 30 mm and 50 mm long were removed from the median nerve. GTMC tubes (supplied by Davis & Geck, Pearl River, NY) 1 mm in diameter and 35 mm or 55 mm long were filled with a 1% solution of 100% collagen type III. The appropriate length tubes were used to bridge the gap between the transected nerve ends. Each end of the tube was secured to the epineurium with a single 10-0 nylon stitch. The procedure was done on the right side first and repeated on the left side in six weeks.

Experiment 3: One investigator in our laboratories has used predegenerated nerves as cellular grafts of up to 10 mm in the rat model. The sural nerves are severed proximally and allowed to remain in situ for seven days. These seven days see the rapid proliferation of Schwann cells in the distal severed nerve [18]. At seven days, the sural nerve is removed and its epineurium and perineurium are surgically removed, leaving endoneurial sheaths or columns of dividing Schwann cells referred to as "Bungner Bands" [21]. This remaining nerve is then placed into a PGA tube and the severed ends of the peroneal nerve are then inserted into this tube.

RESULTS

Experiment 1: Results appear to indicate that collagen type III has a trophic effect over type I for axonal regeneration. Quantitative histology [22] showed no significant difference between the two repair methods by axonal counts and fiber diameter histograms with good axonal regeneration across the grafts and into the distal segments (Figure 1). Electrophysiologic data are presented in terms of the integrated mean compound action potential (IMCAP) in ANG-implanted and autografted limbs:

Type I:III ratio	IMCAP (% normal) ANG	autograft	N
100 : 0	42.5	32.5	2
75 : 25	41.5	56.5	2
50 : 50	52.0	38.3	3
25 : 75	61.0	71.0	2
0 : 100	80.0	41.3	3

Experiment 2: Although only one animal has been tested to date, results show that we can obtain regeneration in ANGs containing collagen type III in the primate.

Experiment 3: Early results suggest that increasing the number of Schwann cells in an autograft by predegeneration improves regeneration of axons into the distal segment.

CONCLUSIONS

Our preliminary results show substantial regeneration through collagen-containing ANGs. Type III collagen appears to be superior to type I. GTMC is considered better for the sheath tube because it is completely hydrolyzed as with PGA but is metabolized slower [23] and is much softer.

In addition to the positive role of specific types of collagen, investigators have noted important cellular and non-cellular factors. For example, Schwann cells apparently produce neurotrophic factors which stimulate axonal growth [9]. Our laboratory is presently growing Schwann cells in culture, and in future work will inoculate the bicomposite ANG with a Schwann cell population.

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FIGURE 1: Regenerated axons 5 mm distal to graft. Original magnification 450X.

34.5

POSITIVE-LOCKING COMPONENTS AND HYBRID FITTING CONCEPTS FOR PERSONS WITH HIGH LEVEL BILATERAL ARM AMPUTATIONS

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ABSTRACT

The fitting of multi-functional prosthetic arms to persons with high level and bilateral amputations continues to be a significant challenge. Recent advances in clinical fittings emphasizing body-powered components and hybrid mechanical/electric systems are described and discussed.

BACKGROUND AND INTRODUCTION

The availability of electric-powered positioning components (elbows and a wrist rotator) within the last decade has increased the options for providing function to persons with high level, bilateral amputations. However, basic improvements in the motors and drive mechanisms of these components are still needed to make them faster, lighter, more rugged, more powerful, and less energy consuming. Improvements are also needed in their control, especially as their mechanisms are made mechanically more dynamic and responsive.

Body-powered and manually-positioned arm components continue to have great value in prosthetic restoration. In spite of many deficiencies in these components, they offer a number of significant features for the appropriate user. Through the control cables which harness body movements and forces to the components, the user is able to take advantage of his or her intact musculo-skeletal and sensory systems. The cables serve as bi-functional linkages providing both control and feedback—of position, velocity, acceleration, and forces. Consequently, there can be close coupling between the user and the prosthesis reducing the mental effort required in using the prosthesis. Mechanical prostheses are also generally simpler, lower in cost, more rugged, and easier to repair than are prostheses with electric-powered positioning components.

There are few guidelines, however, for the application of body-powered and manually-positioned components in an integrated fashion to achieve multi-joint positioning of a prehensor. Only a small number of clinicians and centers have been able to exploit these components fully. Notable clinicians in this regard are George Robinson and Jim Caywood, of Robin Aids Prosthetics[1], who have been instrumental in the application of positive-locking wrist-positioning components and have made significant advances in fitting mechanical prostheses to persons having high level arm amputations. Inspired by their successes, we have been modifying and refining their techniques in a joint effort between the Northwestern University Rehabilitation Engineering Program and the Orthotic/Prosthetic Clinical Service of the Rehabilitation Institute of Chicago.

METHODS

Two clients of the Service are presented to illustrate the components which we are applying and the fitting concept we are developing.

Bilateral Above-Elbow Fitting

Client A is shown in Figure 1. He has bilateral A/E amputations with sufficiently long residual limbs that much of his physiological shoulder motion has been conserved by proper socket design. Friction humeral rotation joints and body-powered elbows operated by dual-control systems have been used bilaterally.

His right prosthesis, the dominant arm, incorporates the Robin Aids Forearm Setup, which includes positive-locking wrist rotation and wrist flexion components. The wrist rotation lock is actuated by a lever extending outside the medial wall of the forearm just distal from the elbow joint. When unlocked (e.g. by adducting the arm and pressing the lever against the body), a wound spring applies a torque to pronate the wrist. A counter-torque is provided through the routing of the control cable to the split hook prehensor. Relaxing the cable allows the wrist to pronate, but pulling on the cable causes the wrist to supinate. The wrist flexion lock is actuated through a cable routed to a lever (hidden by the client's shirt) mounted on an extension of the anterior-superior surface of the socket. The lever is operated with the chin. A rubber band applies a torque pulling the wrist into extension when unlocked. The counter-torque is

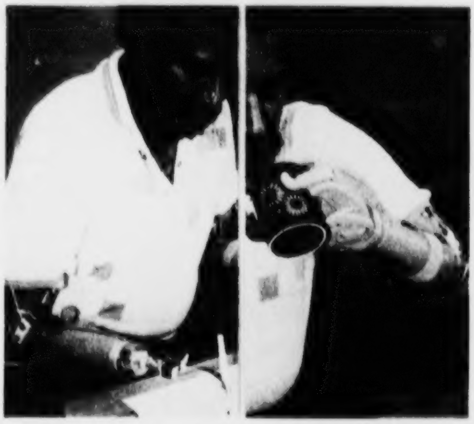

Figure 1. Client A with hybrid bilateral above elbow prostheses. Right arm is body-powered; left arm has electric prehensor.

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[1] Robin Aids Prosthetics, Vallejo, CA

again provided through the routing of the control cable. Tension on the cable will pull the wrist into flexion. Therefore, by unlocking either of the wrist components and applying appropriate tension through the control cable, the client is independently able to orient the prehensor with two degrees-of-freedom.

The left prosthesis is configured to assist and supplement the function of the right prosthesis. A single degree-of-freedom—rotation—is provided for orientation at the wrist. The prehensor is a Greifer[2], a non-hand-like electrically-powered device, controlled by a single-site myoelectric system. This prehensor was selected to provide gripping forces (in excess of 20lb_f) sufficient to handle drinking cups and other objects that could not be gripped securely in the right voluntary-opening split hook prehensor.

Bilateral Shoulder Disarticulation Fitting

Client B is shown in Figure 2. On the right side, he has a true shoulder disarticulation level amputation. On the left side, he has an amputation through the neck of the humerus, which is prosthetically fit as a shoulder disarticulation because the residual glenohumeral motion offers inadequate leverage.

The right prosthesis is completely body-powered and is a modification of the Robinson-Caywood techniques. The arm has a positive-locking cable-operated elbow, a positive-locking wrist rotation unit, a positive-locking wrist flexion unit, and a cable-operated split hook. As with the Robin Aids Forearm Setup, the wrist rotation unit is spring-biased for pronation and the wrist flexion unit is spring-biased for extension. Again, by routing the control cable off-center of the axes of rotation of the wrist components, the client is able to apply counter-torques to orient the prehensor. The locks of both wrist components are released by chin-operated nudge controls mounted on an anterior extension of the socket. The elbow lock is tethered to a waist belt and is cycled by shoulder elevation.

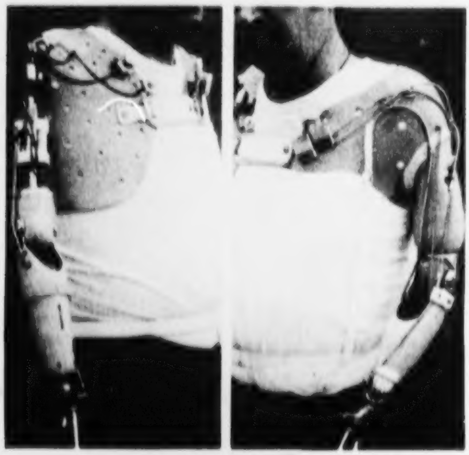

Figure 2. Client B with hybrid bilateral shoulder disarticulation prostheses. Left arm is body-powered; right arm has electric components.

Selective use of the positive-locking components (elbow and wrist units) enables the client to position and orient the prehensor and to open the prehensor with a *single* control cable, actuated by biscapular abduction. Except for a friction humeral rotation joint, the client does not need to use objects in the environment or pressure against his body or lower limbs to produce torques to move the components—*positioning can be done in free space.*

The right prosthesis incorporates an electric elbow[3]; an electric Prehension Actuator[3]; and shoulder, humeral rotation, and wrist rotation friction joints. The elbow and prehensor are controlled by chin-operated switches mounted to the socket. This arm is used to assist the function of the body-powered arm, to hold objects in place or to hold or stabilize an object while the body-powered arm is used to manipulate the object.

DISCUSSION

Building on the techniques of Robinson and Caywood, we have developed an alternative, hybrid approach to high level bilateral prosthetic fittings—fitting the dominant side with a multi-function body-powered system and the non-dominant side with some combination of electric and mechanical components.

Integration of positive-locking components in the body-powered arm provides for great variation and relative ease in positioning and orienting the prehensor and, when locked, for rigidity against displacement due to forces associated with the use of the arm.

Use of electric-powered components in the non-dominant arm eliminates interaction between the control systems of the two prostheses. Problems of cross control and inadvertent movement of a joint, associated with complete body-powered systems for high level bilateral fittings, are avoided.

Emphasizing the use of body-powered components over electric-powered components utilizes the person's intact proprioception and results in a generally lighter, more durable, and more easily repaired set of prostheses.

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35.1

AN APPROACH TO MOBILITY AND COMMUNICATION VIA SEATING: A CASE STUDY

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ABSTRACT

For the severely disabled client, simultaneously attaining various functional goals in one system remains hard to achieve. This case study demonstrates a combined team effort in creating a system, whereby the client's mobility and communication needs were met. Therapeutic and technical possibilities as well as security, esthetics and patient care were taken into consideration.

INTRODUCTION

Marie Enfant Hospital is a pediatric rehabilitation center located in eastern Montreal which offers services throughout the province of Quebec. It's clientele consists of physically disabled children who receive services via programs categorized according to pathologies (ie. cerebral palsy, muscular dystrophy, head injury, spina bifida...). Specialized programs such as seating and augmentative and alternative communication (AAC) were developped due to the extreme variations and complexities of the pathologies, the client's age range and their respective needs. In order to successfully meet these goals, a coordinated approach between these two programs as well as the technical team was essential.

The following case study will describe how Mario, a 24 yr old non-verbal cerebral palsy client, benefited from this approach.

BACKGROUND

Mario presents a severe spastic quadraplegia with athetosic and dyskinetic movement and myopia for which he wears corrective glasses. He came from a rural setting about 200 miles north west of Montreal and lived with his parents. He was referred to our center for evaluation of his communication skills, being that it is the only center in the province to offer a multidisciplinary team approach to AAC.

The initial evaluation by the therapist in the AAC program revealed that Mario had developped some communication skills. These skills were insufficient to meet his needs and those of his immediate environment.

It was noted that he:

- could verbalize a "yes" or "no" response
- was a passive communicator
- was a head stick user
- had no permanent communication system and no seating on his wheelchair
- presented severe involuntary movements related to his ATNR
- stabilized himself by placing his arms between his legs

As adequate seating is a pre-requisite for communication, he was automatically referred to the seating program for an assessment. His postural evaluation revealed a severe kyphosis (57°) with a slight scoliosis (11°), severe retraction of the hamstrings resulting in sacral seating. Any attemps to improve his seating posture, created pressure sores on his ischial tuberosities and on his lower back. The installation of a spinal cord stimulator was proposed by the physiatrist, as the best solution in order to improve his seating.

Following this surgical intervention it was observed that there was a reduction of his spasticity globally, this improving his head control and his trunk mobility. It was now possible to fabricate a temporary molded seating to improve his comfort and to permit the evaluation in the AAC program to be completed. In addition an electrical wheelchair assessment was requested.

From the results of these assessments it was suggested to train him with an optical headpointer and review his vocabulary. Secondly, a head controlled electrical wheelchair would be prescribed. Hence, the seating program could now proceed to fabricate the permanent seating, taking into account these additional characteristics: total height reduced to a minimum to allow better access for transportation needs, improved stabilisation of both upper and lower extremities, accessibility for the communication device and solidity of the system because of his extreme strength.

RESULTS

The seating program opted for a modular system since it: allowed more versatility and adjustments both for practical and climatic reasons and resulted in less perspiration than a molded seating would. The specific characteristics of the module were:

- a 95° back to seat angle with a 10° tilt allowing a greater contact area with the backrest of the module and permitting a comfortable tilt of the pelvis taking into account his severe hamstring retraction
- a wedged seat cushion with a 45° angle pelvic strap to prevent sliding
- adjustable and symmetrical thoracic and pelvic supports to maximize his body alignment and control the lateral movements
- axillary straps to improve his trunk extension
- hinged molded knee piece with seat buckle clip to control the effects of the ATNR on his lower extremities and providing a base to anchor a communication device
- a molded arm support with proximal and distal straps to help control the effect of the ATNR on his upper extremities and for security reasons when driving.

Upon reception of his electrical wheelchair a few modifications were necessary for Mario to access the on-off switch and select the forward and reverse direction. A double chin switch from Tash was selected and was mounted on a swing away metal bracket.

As for his communication needs, Mario has a vocabulary of approximately 500 symbols. His head being the major control site, it was challenging to determine how to mount the different devices so that it can be easily accessed and esthetic. With the help of the technical team, it was possible to create an optical head pointer that could be clipped to the rim of the eye glasses. This device is miniaturized, light weight removable and activated by Mario using a switch that is mounted on the metal bracket next to the double chin switch. The support for his communication board was designed to take into consideration these specific characteristics:

- ease of installation
- adjustable and folding
- esthetics
- symbol capacity of 500 -3/4 inch symbols
- quick access to primary symbols while driving
- clear visual field when driving

DISCUSSION

This case study demonstrated how a team approach of various programs resulted in improving the quality of life of a severe disabled individual. Mario was permitted to evolve from a state of dependance to one of partial independance. Having resolved his seating problems, he can now communicate his needs more functionally and explore his environment at his leisure, having discovered the freedom of mobility. A challenge remains for him to fully integrate and apply his new skills in his environment.

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35.2

THE TAMARA SYSTEM : Integrated control of mobility, communication, and environment

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ABSTRACT

This paper describes a microprocessor based system for control of an electric wheelchair, voice output communication aid, and environmental control. While this project was instigated for a particular individual, many concepts used can be transferred to the mobility, communication, and control needs of other individuals.

BACKGROUND

Tamara, "Tammy" is a 29 year old lady with severe cerebral palsy. Last year she marked her 25th year at Pauls Valley State School, a residential facility. Previous communication systems included a language board that Tammy selected with her foot. Next, staff was trying to determine how she could operate a single switch to control a Zygo 16 communicator. Because she arched her trunk to say yes, a vendor suggested a normally closed switch could be placed underneath her, and activated when she arched her trunk. This would be tiring for use on an extended basis and Earl Gaddis's presentation on body mounted switches (1) was remembered. While Tammy had poor proximal upper limb control, she was able to squeeze and release her hand on request. A splint for one hand incorporating a microswitch was constructed for scanner control. Next a splint for the other hand was constructed and used for X-Y control of the Zygo 16, or simultaneous control of a communicator and electric train set (2). Due to her success, an ACS Speechpac was purchased for her use and her vocabulary is improving steadily.

Staff begain asking how Tammy could control an electric wheelchair. Again, finger control was explored. A linear hall effect magnetic sensor was attached to a hand splint and connected to a bar graph display. From her initial ability to vary the display by moving a finger mounted magnet, we were encouraged to explore this as a mobility control option.

At the time, Tammy had flexion and extension of a finger on one hand but only flexion of a finger on the other hand. For this reason, a nonlinear circuit was designed for directional control (3). As her therapy progressed, Tammy was able to flex and extend both fingers rendering the nonlinear circuit unnecessary. Due to the availability of a CP-1 wheelchair controller from Du-It Controls, an interface circuit was developed to translate the linear output of the hall effect sensors into switch signals for the CP-1. A scanning mode selection circuit was added allowing the finger sensor output to be directed to the wheelchair, speech communicator and a standby mode. Recently the system was turned over to occupational therapy for training. To simplify training, the mode selection scan was bypassed.

First. generation Tamara System, showing handsplints and display, without communicator

CURRENT DEVELOPMENTS

Attention for Tammy's system has turned to developing the next generation, which will be microprocessor based.

Design changes will include the following:

(1) Handsplints: Presently a finger mounted sensor is moved between two magnets, producing a variable voltage linearly related to finger position. This will be changed to a finger mounted magnet moving between two sensors, easing setup.

(2) A microcontroller board that interprets the Forth computer language will be used to translate the sensor and mode switch inputs into desired actions. Use of the Forth programming language will allow easier reconfiguring for each users needs.

(3) A programmable motor control section will be used. This section will be supplied with the desired velocity and acceleration. Using feedback from wheel position sensors, the motors will be controlled to provide the desired response.

(4) A display including a 5 X 5 array for finger position, a 6 light mode indication and indicators for low battery, and low speed range will be developed.

(5) As discussed in the accompanying Vectorplane paper (4), there will be a means to contour the response to control inputs.

(6) Electronic potentiometers are used in this design to adjust gain and zero of the sensor inputs. These potentiometers can store the desired settings between uses, or the controls span could be recalibrated before each use. Recalibrating before each use allows the system to accommodate variations in hand placement within the splint or day to day changes in finger range of motion.

(7) As a further refinement, a radio link could be substituted for the cable between the system and host computer. This set up would allow easier modification of control parameters during set up. Another use could be determining a potential user's response to movement by remotely controlling the wheelchair.

By requiring a computer with the proper software to be connected to the power unit in order to modify control parameters, "screwdriver fairies" who would change settings without a therapist's consent are stymied, a consideration in some settings.

SUMMARY

A very versatile microcontroller system has been developed for integrated control of communication, mobility and environmental control.

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35.3

RESIDENCY PROGRAM IN REHABILITATION TECHNOLOGY: A MODEL FOR THERAPIST POSTGRADUATE EDUCATION IN SEATING AND MOBILITY

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ABSTRACT

A model program is described which was established to provide clinical education in the field of seating and mobility. A paid work-study program consists of part time delivery of direct patient care and a part-time educational experience in rehabilitation technology services for a three to six month period. The program provides the experienced therapist a non-traditional method of clinical education.

The Center for Rehabilitation Technology established a clinical residency model designed to achieve several goals in a rehabilitation and research hospital setting:

1. To disseminate to other centers the clinical and administrative skills and information needed to establish or advance a specialized program such as one in seating and mobility.

2. To provide a unique opportunity for specialized training in rehabilitation technology to experienced clinicians interested in advancing their expertise.

3. To provide a vehicle for retention and/or recruitment in an increasingly competitive job market for skilled physical therapists.

The program was designed for physical therapists with a minimum of one year of experience in rehabilitation preferably with patients with neurological involvement. The paid work-study schedule provides for half-time patient care on a disability specific unit through the Physical Therapy Department. Residents can be assigned to any specialized unit, and although some facility and department orientation may be essential, previous rehab experience minimized the amount of supervision and time required for effective management of a 50% case load.

The 3-6 month program (exact length being determined in advance) incorporates specific goals, and both structured and self-directed clinical experiences based on the applicant's background in seating and mobility and personal objectives. Clinical opportunities, intradepartmental and interdisciplinary collaboration, and project development address the following areas:

. Multidisciplinary team delivery of technology services
. Commercial and customized options, materials used for fabrication, and the potential and indications for rehabilitation engineering consultation, modification and/or device development.
. Methods to assess not only specific clients but to assess new or prototypical devices and provide valid clinical feedback to industry.
. Strategies and resources for both computerized and traditional access to information, materials, and techniques.
. Administrative issues such as funding policies, wheelchair fleet/adaptive equipment shop management and quality assurance.
. Research design, tools and methods applied to issues in seating and mobility.

This residency represents a unique model which addresses two needs:
(1) Comprehensive exposure and education in technology for a clinical therapist wishing to explore an alternative specialization to direct patient care or administration.
(2) Intensive learning opportunity for clinicians currently delivery technology services wanting to upgrade their skills.

The program provides the experienced therapist an essentially subsidized method of clinical education unachievable in traditional continuing education courses and without full or immediate commitment to a permanent change in job or location.

In our setting the residency program is

split between two departments. During periods of staff shortage, the physical therapy department gains by adding a half-time clinician in a position which may well remain open without the benefits of rehabilitation technology education attached. The CRT fulfills one of its mandates to provide professional education. As more residents participate in this program, benefits in reduction in patient waiting lists (and increased hospital revenue), in educational effectiveness and in recruitment will be weighed against salary, time and resource cost to both departments and the institution.

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35.4

RETROFITTING: AN UNNECESSARY EXPENSE

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ABSTRACT

In the United States there is disparity in evaluating, recommending, and fitting seating and mobility systems. At one end of the spectrum is the clinic based program with a highly trained team of specialists and vendors. The prescription method filled by the lowest bidder is at the other end of the spectrum. Community clinicians must deal with retrofitting inappropriate seating and mobility systems, and the costs in terms of equipment and manpower are high. A cost analysis demonstrating the ramifications of omitting a specialized cushion is discussed.

INTRODUCTION

Most large hospitals in cities have formal seating programs, utilizing a team approach to provide evaluations, recommendations, and fittings of seating and mobility systems. The expertise of individuals and teams varies in terms of background, education, experience, and continuing education.

Many hospitals in rural settings and regional clinics sponsored by state agencies do not utilize community therapists in the decision making process. Some of these therapists have expertise similar to those therapists in formal seating clinics; an added benefit is knowledge of the specific clientele. Often measurements are taken, placed on a prescription form, and filled by the local vendor submitting the lowest bid. Retrofitting inappropriate new wheelchairs in the community becomes costly for all involved.

METHODS

A.S. is a 13 year old young man with a diagnosis of myelodysplasia and hydrocephalus and a past medical history of brittle bones and Harrington rod placement. Attending junior high school, he is in an classroom for students with educable mental disabilities and has a half time extraordinary care aide. A.S. is independent in transfers, dressing, eating, and grooming; this summer he became responsible for his own bowel and bladder care. As the oldest of three children A.S. has some responsibility for his siblings and has been assigned chores around the house.

A.S., independent self propelling wheelchair user, spends time at home sitting on the floor and sits in the back of the family station wagon for trips. In his old wheelchair A.S. was observed to sit with his hips abducted and externally rotated, his pelvis in posterior tilt, and a forward lean of his trunk to conterbalance the pelvic tilt.

During the past year A.S. outgrew his second wheelchair. The family went back to the vendor from which they had purchased both wheelchairs, having been referred originally by a state agency that assisted in the payment of the first wheelchair. A.S. was measured by the vendor and the prescription sent to A.S.'s physician for signature. A lightweight wheelchair with a hard seat, plywood with one inch open cell foam and vinyl covered, was ordered and delivered.

RESULTS

During routine visual inspection A.S. noticed a reddened area on his buttocks. He was taken to the physician and released with the precaution to watch the area. Two weeks later A.S. ran a high fever; probing the area the physician located an abcess. Placed on antibiotics, A.S. was instructed to remain in positions other than sitting until the area healed.

Home health services were instituted for daily dressing changes at a total charge of $1136.00, medical supplies including medications cost $168.04 and three physician visits were $135.00. Medical related expenses totaled $1439.04.

A.S. was home for 10 weeks and missed 37 days of school. After 10 days A.S. received 27 hours of homebound instruction from a tutor at $405.00. During his absence, A.S.'s share of his extraordinary care aide's wages, $906.50, was paid though services were not rendered. A.S., treated regularly at school by therapy assistants, was seen by therapists who were called in to retrofit the problem; his mother who works for the district missed five days from work. School related expenses totaled $1761.50.

DISCUSSION

The community therapists worked with the family assessing A.S. and his seating needs. Not only did A.S. require a contoured seating system for postural management, but because he has no sensation in his lower trunk and legs, he needed a system for pressure sore management (2). A hybrid system, the Jay Cushion which meeting both needs, was recommended. This specialized cushion can be removed from the wheelchair and used for his other positioning requirements at home and in the car.

CONCLUSIONS

The Jay Cushion was a $300.00 solution to a $3200.54 problem that should not have occurred. With escalating health care costs, third party payers are becoming increasingly cognizant of the need for determining the level of expertise behind recommendations for the purchase of high cost durable medical equipment (3). In answer to these needs, the University of Tennessee Rehabilitation Engineering Program at Memphis has undertaken the task of certifying individuals as seating and mobility specialists.

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36.1

TRAINING OCCUPATIONAL THERAPISTS IN REHABILITATION TECHNOLOGY

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ABSTRACT

The occupational therapists role in rehabilitation includes adapting tools for use by persons with physical handicaps. While therapists are generally comfortable with construction of active and dynamic splints, or with modifying handles on basic tools to increase function for the person with upper extremity dysfunction, they are less fluent with modification of computer interfaces for access by the handicapped person. The primary cause of this lack of fluency appears to be limited education in the adaptation of high technology devices to the needs of the handicapped individual.

To address this issue, the University of Washington has added a course in the occupational therapy curriculum which presents an introduction to computer systems adaptations and computer applications in rehabilitation.

INTRODUCTION

While there are currently a wide variety of adaptive interfaces to allow the handicapped individual access to computers, and a wide variety of empowering computer-based tools to allow the handicapped individual to compete in an ever more computerized workplace, there is a severe weakness in the systems to evaluate the needs of the handicapped individual and to match him or her with the appropriate adaptive devices. The occupational therapists role in rehabilitation includes adapting devices for improved access by the handicapped individual to improve function in daily life tasks. Unfortunately, the level of awareness in the rehabilitation community of computer based tools and of computer adaptations lags markedly behind the level of innovation in the computer field.

BACKGROUND

A nationwide study has shown that there is a shortage of occupational therapists who have sufficient computer competency to be able to utilize computers as a therapeutic modality, as an administrative tool, or to provide training on computer use to persons with physical handicaps. Of the 298 centers surveyed, 155 reported that computers were not used in their therapy programs. The primary reasons listed were "lack of computer literacy" and "lack of information on how to begin." (Spicer, McMillan. 1987) The reports from graduates of the University of Washington Division of Occupational Therapy from the years 1982 to 1986 show that 53.6% use computers in clinical administration, and 56.5% use computers in patient treatment. The most common request for improvement in the academic program after "more hands-on patient experience" was for more training in computers and computer applications. (Kanny & Greenberg, 1987)

In response to this need, the University of Washington Division of Occupational Therapy has established a new course "Technology in Rehabilitation", which was first taught in Spring Quarter, 1989. This is an entry level course providing basic background information on computer adaptations and applications for improving the independence and quality of life of the handicapped individual.

TECHNOLOGY COURSE AND LABORATORY

Preparatory Course

To introduce the students to basic computer literacy, an independent study module was prepared which requires each student to manipulate a standard document on three different word processors on three types of computers. Even those students who enter the occupational therapy program with some basic computer skills will generally be familiar with only one type of computer, and with only one type of productivity software. This exercise will provide the student with basic operational experience with diverse computer architectures and operating systems. In addition to teaching the students the operation of basic productivity software on different computer designs, the exercise provides experience in reading computer documentation. The exercise is completed as a one credit independent study prior to entering Technology in Rehabilitation.

Computer Laboratory

As a medium in which to provide training in rehabilitation technology, the Division of Occupational Therapy established a Computer Laboratory. This laboratory contains computers representing the three types most frequently found in clinical practice: Apple IIGS, Apple Macintosh, and IBM Compatible. The laboratory also contains examples of adaptive interface devices most frequently used in adaptation of computers for persons with severe disabilities. These include single switch input systems, enlarged and adapted keyboards, and scanning and pointing systems.

The laboratory is used for both demonstration and hands-on experience with the adaptive interfaces presented. Laboratory sessions include construction of specialized switches, connection of adaptive interface devices to the productivity software via the adaptive interfaces

Technology In Rehabilitation

The "Technology in Rehabilitation" course is organized in three sections. The first is a historical perspective of technology in rehabilitation, including technological invocation, legislation supporting technology access, and clinical practice. The objective of this section is to familiarize the student with the historical, legal, and ethical issues relating to rehabilitation technology.

The second segment of the course provides background information and hands-on experience with several common adaptive interface devices. The students practice setup and use of devices such as the Adaptive Firmware Card, the Personics Headmaster, and the AID + me universal interface. After the adaptive interfaces are set up, the students use them to communicate with standard productivity software. The objective of this portion of the course is to provide the students with experience in using common adaptive interface systems with direct selection, scanning, and pointing systems, and to allow the students to experience the problems confronting the handicapped person wishing to use a computer.

The final segment of the class consists of a series of lectures by clinicians using advanced technology in the Puget Sound area. These lectures include presentations on powered mobility and seating systems, augmentative communications, cognitive and psychomotor retraining, and computerized workstations. In addition, the laboratory component provides opportunities to set up computer systems for persons with simulated disabilities. The objective of this portion of the course is to familiarize the student with the range of applications of advanced technology in clinical practice.

DISCUSSION

Because this program is in its infancy, it is too early to be certain that the additional training will improve clinician competency. The purpose of this course is to provide entry level skills in computer technology in rehabilitation. We are aware that the introductory course will not be sufficient to provide expertise in computer adaptations. To further facilitate clinical expertise, we are pursuing support for a program to provide graduate and continuing education training in basic computer skills, and advanced training in implementation of adaptive interfaces on computers.

The American job market is becoming increasingly computerized. Conservative estimates suggest that by 1990, 60% of all jobs will require access to computers. For the person with moderate to severe physical disability, these "desk" jobs requiring computer access are often the only options available, as the majority of non-computerized jobs depend on intact physical status. To assist the person with a severe physical disability to return to the job market, it is vital that the occupational therapist be knowledeable about the adaptations available for computer access, and comfortable in providing these for the injured worker.

The implementation of computer technology in the rehabilitation process has been hampered by lack of training in this technology. By providing entry level training in computer adaptation, we are providing a "first step" toward preparing clinical experts in rehabilitation technology.

ACKNOWLEDGMENTS

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36.2 DEVELOPMENT AND EVALUATION OF COMPUTER-AIDED INSTRUCTION FOR SPINAL CORD INJURY PATIENTS

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ABSTRACT

The Development and Evaluation of Computer-Aided Instruction for Spinal Cord Injury Patients is a new pilot project administered by the VA Research and Development Service. The purpose of this project is to develop and evaluate a tutorial on Autonomic Dysreflexia using advanced computer technology to facilitate independent learning in spinal cord injury (SCI) rehabilitation. This tutorial is the first in a series of computer-aided instruction (CAI) tutorial directed at the learning needs of the spinal cord injured population.

INTRODUCTION

Spinal cord injury rehabilitation involves psychosocial adaptation, and the acquisition and assimilation of new knowledge. It also requires that the patient learn new ways of doing everyday tasks. Consequently, patient education is an integral part of most SCI programs. Several instructional methods are used, alone or in combination, to introduce new materials or teach new skills. Among these are one-on-one, formal classroom, and informal peer instruction. Traditional instructional tools, such as audio-visual and written materials, are often used in patient education. Unfortunately, use of these materials by individuals with manipulation deficits requires the assistance of another person and eliminates the possibility of truly independent study.

CAI can provide another option for learning; an option that may be preferred by patients in all stages of rehabilitation. CAI not only allows for independent computer usage (through a variety of user interfaces), but it permits privacy in the learning environment, and makes instruction available when the patient is ready to learn.

BACKGROUND

Autonomic Dysreflexia

Autonomic Dysreflexia can occur in individuals with a spinal cord injury above the T-7 level (approximately 65% of all spinal cord injuries). An overdistended bladder or bowel can set in motion a series of physiological events that result in this life threatening syndrome. In order to keep the patient out of danger, immediate intervention is required; therefore, it is important that everyone who has contact with the patient at risk learns about Autonomic Dysreflexia, why it occurs, and how to respond to different situations. Hospital staff not only must be aware of how to address the syndrome, but must also feel confident in the patient's understanding of the syndrome and ability to deal with any symptoms that may occur.

CAI In Patient Education

Computer-Aided Instruction is currently being used in health care organizations around the country to teach diet, drug, and general health information. Nurses, physicians, pharmacists and other health professionals are beginning to use the computer for teaching and testing patients with a variety of medical problems such as heart disease, rheumatoid arthritis and diabetes.

The major limitation of CAI for patient education appears to be a lack of appropriate software (1). This is no different for SCI patient education. Currently the only CAI available is that which comes with the *VIVA!* system— a voice actuated hardware and software package that is available on a lease-only basis (2). Unfortunately, financial constraints, and/or billing systems that do not permit patient charges on a per-use basis, preclude many centers from using the *VIVA!* system. Until another system becomes available, the 22 VA Spinal Cord Injury Centers will continue to have a need for CAI software that can be purchased or distributed at cost, and can be used with commercially available hardware.

This project demonstrates a continued interest in interactive computer-based education at the Palo Alto VA Medical Center. The Interactive Learning Lab, an early study of interactive video for patient education, examined the hypothesis that the rehabilitation process is enhanced when patients have the opportunity for independent self-instruction. In the clinical evaluation of the Learning Lab, Tang found that independence in the learning environment is strongly desired by patients, and can occur with the use of sophisticated assistive devices that encourage independence (3).

In the past year and a half, over 30 SCI patients have been trained to use several applications on the Macintosh Plus including word processing, graphics, spreadsheet and database management programs. In the Palo Alto SCI patient rehabilitation program, the computer is used both as a therapeutic tool and vocational aid. Individuals are required to identify, make use of, and adapt, their existing functional capabilities in order to successfully use the hardware and complete the training. With the support of a therapist and a good introduction to its operations, the computer becomes an excellent educational, vocational and therapeutic tool.

METHODS AND MATERIALS

The Computer-Aided Instruction tutorial on Autonomic Dysreflexia is being developed for use on the Macintosh personal computer. The Macintosh has been selected for its advanced graphic capability, the variety of available user interfaces, and the wide acceptance and availability of this particular computer in the community at large.

The Macintosh accepts input from an assortment of control interfaces. This makes it possible for all patients to interact independently with the computer regardless of the level of their disability. Individuals with good hand function can control the computer through the mouse and standard keyboard combinations, while individuals with limited hand function (SCI levels C 5-7) can use a Lynx trackball. The individual with wrist extension or pronation/supination ability can use a modified U-cuff to type and to press the selection button on the trackball. Individuals with no hand function (C 1-5) can use the MacIntyre Lipstick or Personics HeadMaster to emulate mouse and keyboard functions.

The Autonomic Dysreflexia tutorial is being developed in parallel using two different applications: CourseBuilder (Telerobotics) and HyperCard (Apple Computer). CourseBuilder is an authoring package which allows for the development of stand-alone educational tutorials; HyperCard is both an authoring and advanced programming tool. (See Figure 1 for a comparison of their features.)

Features	*HyperCard* [a]	*CourseBuilder*
sound	x	x
animation	x	x
color		x
programmable	x	
full screen use (Mac II monitor)		x
documentation	x	x
student report generator		x
prototype training and testing formats		x
supports multiple branching		x
creates stand-alone product	x	x
interface with other Macintosh applications	x	
adheres to Apple user interface guidelines	x	
developer's support	x	x
third party software available	x	
memory requirements	1 Mbyte	512K+800K drive
cost	\$ 49[b]	\$ 395

Figure 1. a) MacRecorder (Farallon), a digital sound recording system, and Videoworks (MacroMind), an advanced animation program, are being used in conjunction with HyperCard. b) Additional costs include MacRecorder (\$199) and Videoworks (\$295). Neither is required to use the final product.

DISCUSSION

Formal evaluation of the Autonomic Dysreflexia tutorial is scheduled for Summer 1989 to coincide with the quarterly patient education cycle at the VA Spinal Cord Injury Center. 30 patients from the SCI Center, their families, personal attendants and the SCI staff will participate in the evaluation. Subjects will be given pre- and post-tests to measure content-learning followed by an interview to obtain their opinions of the tutorial. Attitudes toward CAI as a teaching and learning tool will also be assessed. Each version of the tutorial will be evaluated with respect to: ease of development; quality of graphics, sound, and animation; and ability to keep student records. It is also important that the tutorial be easy to modify, and practical to customize, in meeting the informational needs of different audiences.

Future plans include the development and evaluation of CAI tutorials on such topics as: Spinal Cord Injury Facts, Neurogenic Bowel and Bladder, Skin Management, Sexuality, Medications, Increasing Hand Function through Therapy and Surgery, and Adaptive Equipment and Its Function.

CONCLUSIONS

The personal computer, with its capacity to support a variety of control interfaces, makes independent learning for all SCI patients possible. In addition, computer-aided instruction is an excellent adjunct to traditional educational programs for spinal cord injured individuals. Moreover, as computers are increasingly available in the home, CAI lends itself to in-home instruction of personal attendants. (Attendant training may be required as frequently as twice a year over a 30-50 year post-injury lifespan.) It is hoped that patients who have a positive learning experience with CAI will be motivated to pursue computer applications in other educational, vocational and recreational arenas.

ACKNOWLEDGEMENTS

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36.3

EMPLOYMENT OF A NON-SPEAKING WOMAN WITH CEREBRAL PALSY: A CASE STUDY OF INTEGRATED EDUCATION AND SUPPORTED EMPLOYMENT PROGRAMS

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ABSTRACT :

This paper presents a case study of a severely impaired, non-speaking woman with cerebral palsy. Her utilization of rehabilitation technology, including computers, an augmentative communication aid and an electric wheelchair, were essential components of her success within first her school program and then her supported employment program.

INTRODUCTION:

This paper examines a case study of a young woman (M.K.) with a diagnosis of devere spastic quadriplegia, dysarthria and scoliosis. She attended the Meeting Street School program at the Easter Seal Society of Rhode Island until she recently turned 21 years old, when she entered the Easter Seal Society's Supported Employment Program. Through the training and support of these programs and with the assistance of rehabilitation technology, she now is employed part-time in a productive, mainstream job in the city of Providence, R. I.

DISCUSSION:

This paper discusses M.K.'s school training, the technology and adaptations she uses, her supported employment program and her current job. It was during her school programming that M.K. began to use a variety of technological aids. These devices include computers (Apples and IBM PS/2's) with adaptations, an augmentative communication aid (consisting of a Toshiba laptop computer, Words+ Equalizer software, a TASH penta switch and a portable DECTalk speech synthesizer) and an electric wheelchair (Invacare). During her school program, M.K. participated in a functional educational curriculum which emphasized vocational preparation, communication skills, academic learning, self-advocacy issues and community-based training. Individulized physical therapy, occupational therapy and speech-language therapy were integrated into her educational plan through a multi-disciplinary team model.

The last months of M.K.'s school experience were spent in vocational assessment and transitioning to a Supported Employment Program.

When she turned 21 years of age, M.K. formally entered the Supported Employment Program. A formal vocational assessment identified her functional abilities, vocational interests and needed adaptations and modifications. Due to M.K.'s severe physical and communication impairments, traditional vocational assessments were deemed inappropriate. The assessment process, including a situational assessment, consisted of a functional work assessment inventory, an occupational therapy evaluation, a speech-language therapy evaluation, a work performance profile, an occupational interests inventory and an adaptative equipment assessment. M.K. was placed in a part-time job in a regular office after matching her skills, her interests and possible job placements. Significant efforts were made to address transportation and workplace accessibility issues with assistance from a social worker and a vocational rehabilitation counselor. Her specific work responsibilities will be described as will be the assistive devices and worksite modifications required to enable her to complete them.

ACKNOWLEDGEMENTS:

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COMPUTER DRAFTING FOR THE DISABLED

36.4

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CAD (Computer-Aided Drafting) has made it possible for people with physical disabilities to express their ideas graphically. A program designed to provide basic drafting skills to people who can not otherwise use standard drafting implements is in operation at the County College of Morris (CCM). The program, called CEDD (Computer- Enabling Drafting for the Disabled) is demonstrating that a high-level quadriplegic with good head control can draft at about 95% of the efficiency of an able-bodied person.

INTRODUCTION

There is a need for people with good fundamental drafting skills and who are CAD literate. This need is supported by the numerous newspaper help-wanted advertisements, as well as information provided by the CCM Career Services Department, and industry advisors to the CCM Mechanical Engineering Technology Department.

CAD has made it possible for people who cannot manipulate the standard drafting implements, T squares, triangles, scales, etc., to draft using a variety of computer access modalities. Our experience with three classes has shown that a person with good head movement or with good control of one arm, can draft at about 95% of the efficiency of a non-disabled drafter. People without good head control can draft, but at reduced efficiency.

The CEDD program was implemented during the 1987 fall semester with a class of five students. In the succeeding two semesters, ten additional students were accepted into the program. Of these fifteen, all but one successfully completed the program. Five additional students are currently enrolled in the program.

PROGRAM OBJECTIVES

The objectives of the CEDD program are to:

- Teach the students with disabilities the fundamentals of drafting and CAD.
- Permit these students to be mainstreamed into more advanced drafting, technical and engineering curricula, thus permitting them to pursue degrees in engineering and technology, and certificates in CAD technology.
- Provide the training which will open vocational opportunities for the students as drafters, technicians, and engineers.
- Develop a prototype technical work station for use by people with disabilities.

EQUIPMENT DESCRIPTION

CAD Hard/Software: HP 310 Series Computers with 3mb RAM and 20mb hard disc storage capacity were used to run HP's Mechanical Engineering (ME10) CAD software. Nineteen-inch high-resolution color monitors display drawings as the students draft. Multi-colored hard copies of student drawings are produced on plotters.

New Equipment: Recently, five HP RS-16 Vectra (MS-DOS 386 compatible) work stations using 16-inch high-resolution color monitors were installed. The Vectras have 40mb of hard disc storage. They are networked via ARPA networking services to an HP 320 Computer running on a UNIX operating system. The UNIX station acts as the server for the five new stations to handle plotting via an automatic feed plotter, communication by modem, and transfer of files to and from the MS-DOS stations to the older stations.

Independence and Accessibility: With the new equipment, the CEDD students store their drawings on the hard disc and are able to plot their work without assistance. The focus of the CAD room layout and equipment selection was student independence -- the tables are height adjustable; the room has plenty of room for wheel chair maneuverability; door handles are the lever type; the campus has excellent wheel chair accessibility.

Computer Access Devices: Students with control of one arm can often access the computer without a special device if they can grasp the electronic pen. If not, a cuff is used. For two students with weakness in their arm muscles, a sling has been used to support their arms.

Students Without Arm Control: Students who do not have control of arm movement use a Head Master device to access the computer. This device is marketed by Personics Corporation of Concord, Mass. It was originally designed to provide access to a Macintosh computer for word processing. HP engineers modified it so that it connects through a quadrature port into the human interface loop (HIL) of the HP 310 computers. In a similar way, it is also compatible to the new Vectras.

The Head Master converts head movement into cursor movement on the monitor. A special screen menu, developed by another HP engineer, puts the CAD menus and a special alpha-numeric keyboard on the screen. Menu commands and drawing positions are selected using a puff tube connected to a switch on the Head Master. Thus, a student using only head motion can do everything required to complete drawings.

Students with neither Good Head nor Arm Control: One of our students who has athetoid cerebral palsy invented a device he calls a "RAT" (it emulates a mouse) enables him to draft using his head pointer. The student spins two wheels (one for horizontal and the other for vertical cursor movement) to access the computer. He is currently modifying the Head Master EPROM to dampen spastic head movement. It is our goal that, with an eyebrow switch, someone with non-speaking athetoid cerebral palsy can effectively draft using the Head Master.

Use of a Voice Recognition System: Initially, we considered using a voice recognition system to enter CAD commands and text, however, we opted for a screen menu system because of the unreliability of voice systems at the time of the initial program planning. Given the advances in this technology, we plan to reevaluate this option.

CURRICULUM

The CEDD Program is a seven-credit course which combines our Basic Drafting and Introduction to CAD courses. Students learn how to describe an object on a 2-dimensional surface, dimension it, and make sectional and auxiliary views. Faster moving students also learn descriptive geometry. "ENGINEERING DRAWING AND DESIGN" by Jensen is the course textbook.

The classes are conducted three days per week for four hours each day. After two hours, students take a one hour lunch break. the course spans 15 weeks, or one semester. Five students each semester for three semesters have been accepted into the program.

Instruction relies heavily on visual aids displayed on a CAD monitor. Many of the problem assignments are stored on hard disc to be called up by the students to solve. Video tapes of many of the lectures have been made and are available to students for home study.

Practical examination problems are presented to students and are completed on the computers. Problem solutions are then plotted. Understanding of text material is tested with take-home examinations.

ASSESSMENT OF POTENTIAL STUDENTS

Prior to each class, students are given an assessment by an occupational therapist from the institution recommending the student. An evaluation is made of the students' physical, and cognitive abilities. Students are also tested for their visual perception (including spacial relations and figure/ground acuity), and they are interviewed to establish maturity and life goals.

ADVISORY COMMITTEE

An advisory committee, consisting of rehabilitation professionals, engineering managers, and CCM faculty and staff members, have contributed to the CEDD program from its inception. Kessler Rehabilitation Institute, Welkind Rehabilitation Hospital, the Matheny School, United Cerebral Palsy, and the NJ Division of Vocational Rehabilitation are represented on our committee.

The following sub-committees are active:

Engineering Employment Funding
Evaluation Curriculum
Transportation Counseling

ASSESSMENT OF RESULTS OF THE PROGRAM

Since the fall of 1987 fourteen students have successfully completed the course. Five students have cerebral palsy, five are quadriplegics, one is hemiplegic, two have muscular dystrophy.

One student is working as a drafter, one student with MD died, and two students decided to work towards careers in other fields using computers. The others are continuing their studies at the college, having been mainstreamed into the Drafting or Mechanical Engineering Technology curricula.

We started the program thinking that we would be training drafters. However, the number of students who have chosen to continue their education towards earning higher digress is very encouraging. The higher the level of education that a person achieves, the less their disability will mean to a prospective employer. The CCM professors agree that several of the CEDD students are among the best students that we have had the pleasure of teaching. It is gratifying to see that we are helping them to fully utilize their potential.

The CEDD program has been funded in part by vocational education grants P.L. 98-524, Title 11-A distributed through the Office of Community Colleges, N.J. Department of Higher Education.

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COMPUTER APPLICATIONS IN CLOTHING DESIGN FOR PEOPLE WITH SPECIAL NEEDS

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ABSTRACT

Evidence suggests that custom designed garments are ideal for meeting special functional and aesthetic clothing needs of people with disabilities. Traditional methods for producing custom garments are time and labor intensive and provide expensive, one-time solutions to clothing design problems. Fortunately, with recent developments in personal computer technology, custom clothing can now be within the reach of the disabled population.

INTRODUCTION

The design/development project *Computer-Aided Clothing Design for People with Special Needs* seeks to address the clothing and dressing needs of people with disabilities through the application of advanced personal computer technology. This paper will present the results of the design team's efforts since this project was first introduced (1) and discuss the use of various software and hardware in meeting the goals of the project.

BACKGROUND

CAD in Textiles and Apparel

In the past five years, computer-aided design (CAD) has made its way into the textile and apparel industries. Formerly used primarily by engineering and architectural concerns, computers are being integrated into all areas of clothing design and manufacture, from pattern design and grading to the laser cutting of fabric, as apparel makers seek to reduce the cost of production and the time it takes to produce a line of clothing (2).

With the decrease in cost, and the increase in power, that microcomputers have enjoyed in recent years, and with the number of low cost computer-aided design applications that are now available, computers are appearing in small businesses and academic settings as well. In these settings, microcomputers are being used for everything from fashion illustration and pattern design to measurement processing for custom business suits, swimwear, and theatrical costumes.

Work to Date

Since the project's inception, the development team has worked toward applying flat pattern drafting techniques in a computer-aided design environment. AutoCAD (AutoDesk), a IBM PC-based computer-aided design package, and Synthesis (Synthesis, Inc.), a parametric design package that works in conjunction with AutoCAD, have been selected as the software development tools. Together these packages permit the designer to easily modify basic patterns to fit the individual through the input of pertinent body information.

Several basic blocks have been created in the course of the project (for a woman's bodice and skirt, and a man's shirt and pants). (Basic blocks are the foundation of flat pattern design; they are used to develop other designs and to evaluate the quality of measurements taken.) The bodice and skirt blocks are currently being evaluated by students in a custom clothing design class at West Valley Community College.

METHODS AND MATERIALS

Initially, the project relied solely on the use of IBM personal computers, and related CAD applications, for pattern development. With the introduction of HyperCard (Apple Computer), an authoring tool and information organizer, and VideoWorks (MacroMind), a desktop presentation animation package, the project has evolved to include the Macintosh personal computer. It is hoped that by 1990, with the introduction of AutoCAD and Synthesis for the Macintosh, all development for the clothing project will be done on the Macintosh alone.

Figure 1. Body measurements are taken during the initial subject meeting. At this time, the subject is asked about his capabilities, wants and needs with respect to clothing.

As a development tool, the Macintosh is valued not only for its unique user interface and advanced graphics capability, but also for the wide support it enjoys in the clinical community. At the VA Spinal Cord Injury Center in Palo Alto, the Macintosh is used as an instructional tool for therapist and patient education, as well as a therapeutic tool for patient rehabilitation. It is expected that once clinicians are trained in the proper body measurement techniques for custom clothing design, little instruction will be required for them to be able to effectively operate the pattern development package.

Animation and sound continue to be explored as avenues for communicating measurement information. MacRecorder (Farallon), a digital sound recording system, is being used to augment the textual and graphic information in the measurement instruction package. MacVision is being used to capture video images for figure evaluation and animated measuring sequences. These images, or somatographs, give an impression of volume and are useful when analyzing shape and posture for pattern development.

RESULTS

Using HyperCard as a foundation, a figure evaluation and measurement input and processing application has been developed. This package is based on a system of gathering and interpreting measurements that takes into account the left-to-right and front-to-back differences in size, shape and basic structure that appear in most, if not all, human figures (3). While this application will be used to record measurements taken in the development of custom garments, its greatest contribution will be as an instructional tool for those who will be taking the measurements. (Quality of measurements is extremely important when fit is of primary concern.)

During the development of this application, patterns for a suit jacket, pants and shirt were drafted, and garments constructed, for a T-4 level paraplegic male who uses a sports wheelchair. All patterns were developed in parallel, drafted by hand and on the computer. In this way, it was possible to determine where macros, or software shortcuts, could be used to expedite certain procedures and to pinpoint areas that would benefit from further development.

DISCUSSION

A successfully produced custom garment depends not only on the quality of measurements taken but also on the accurate interpretation of the subject's personal preferences and desires. In the process of gathering information on the first test subject, several meetings were scheduled. The first meeting consisted of a measurement session and a personal interview (see Figure 1). The subject was asked to bring one pair each of his favorite and least favorite pants. These garments were evaluated according to their advantages and disadvantages with respect to his dressing and hygiene requirements, storage of personal affects, and vocational and recreational needs. The second meeting involved capturing a silhouette for use in shape and posture analysis. A third meeting was held to determine the fabric and accessories that would be used to construct the final garments.

Once construction began, several iterations were required. As this was the first attempt to make a custom garment with this method, modifications to both pattern and program were necessary. The need for these modifications was determined during prototype evaluation by both the researchers and the test subject. All garments were rated according to fit, comfort, and ease of wear.

CONCLUSIONS

At this time, the measurement package is being used as an instructional aid and first generation user interface for the measurement portion of the custom pattern application. The patterns developed for the test subject are being transformed into master patterns so that other individuals can benefit from the work that has been done. Arrangements are also being made to develop other patterns that will be useful to, and desired by, the spinal cord injury population.

ACKNOWLEDGEMENTS

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APPLICATION OF NEXPERT OBJECT BUILDING TOOL TO UPDATE CUSHFIT EXPERT SYSTEM

36.6

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ABSTRACT

The expert system CUSHFIT, an expert system designed to recommend appropriate cushions designed at Helen Hayes Hospital, has been redesigned using Nexpert Object, an expert system building tool. The resulting expert system matches the sequence of prompts in the original CUSHFIT as closely as possible, while taking advantage of the object-oriented nature of Nexpert Object.

INTRODUCTION

Expert systems, or programs designed to solve problems in a specialized domain in the same way that human experts solve them, have been used successfully in a number of fields, solving problems as varied as determining optimum configurations for computers made by Digital Equipment Corporation to determining in real time whether or not to approve purchases made with American Express cards. Expert systems offer appropriate solutions for solving problems when the problem is well-defined, there are not enough human experts who are knowledgeable in the problem domain, and the problem requires the manipulation of symbolic rather than numerical information (Waterman, 1986).

Similar problems exist in the field of rehabilitation technology. Experts in certain areas are few in number. Often, formal training in rehabilitation technology is minimal or absent in many universities. Expert systems therefore offer great potential for assisting health care professionals in rehabilitation technology whose jobs require them to make formal recommendations about devices or systems with which they may have little familiarity.

It appears that few researchers in rehabilitation technology are exploring the use of expert systems. Napper and Robey (1987) reported an expert system for recommending communication aids. Hsi, et al., first described in 1987 the ADIS expert system for recommending switches for various forms of access. Both of these expert systems are being developed with sophisticated expert system building tools. Shein (1988) is developing an expert system for preparing visual keyboards for disabled persons using the LISP object-oriented language, extending the development time for the system but offering greater control over various aspects of the knowledge acquisition and dissemination process.

Before recent low-cost languages and expert system building tools became available for microcomputers, the only way of developing expert systems was to simulate many of the characteristics of conventional expert systems through the use of a traditional procedural language or application software package. Researchers at Helen Hayes Hospital took the former approach by developing CUSHFIT for IBM PC (Ferguson-Pell, et al., 1984; Trachtman, et al., 1984); Rosen and Goodenough-Trepagnier took the second approach by developing systematic procedures for recommending non-vocal communication systems, outlined in 1983, using Lotus 1-2-3 as the development tool.

BACKGROUND

In 1984, researchers at the Helen Hayes Hospital reported CUSHFIT, an expert system designed to aid therapists in recommending appropriate cushions for patients who tended to have difficulty with pressure sores (1,2). Because no low-cost expert system building tools were available at that time, CUSHFIT was developed as a BASIC computer program on an IBM PC microcomputer. A beta version of this program is now being tested by seating clinics at several sites across the United States.

During the development of CUSHFIT, the investigators noted several difficulties with using a procedural language such as BASIC, which offers limited facilities for building an expert system other than its IF-THEN rule structure. They also had to develop methods of storing information in a form that the BASIC program could understand. BASIC also limited their means of presenting information to the user of the system and of acquiring information from the user. The complexities of the programming instructions created difficulties for maintaining the system so that they could keep current with current advances in cushion technology.

Recently, however, low-cost object-oriented expert system building tools have become available to help knowledge engineers and even domain experts design flexible expert systems.

METHODS

The redesign of CUSHFIT is being performed by the staff of the University of Tennessee, Memphis, in cooperation with the staff of Helen Hayes Hospital. The designated platform for development is an Apple Macintosh II microcomputer using Neuron Data's Nexpert Object expert system building tool. Because Nexpert Object is an object-oriented tool rather than being procedurally oriented (as BASIC is), it offers a number of advantages over BASIC to the expert system developer, such as the ability to create "click-on" button answers for the user's responses, the ability to tailor questions for the users as well as to provide simple reasoning about why it is asking for a particular piece of information, the ability to incorporate graphics in its presentation, the ease by which corrections to the knowledge base can be made, and the ability to interface with other programs when using that program to request, process, or provide information offers an advantage over Nexpert Object.

Nexpert Object possesses several features found in few, if any, other expert system building tools. For example, Nexpert Object stores its expert systems in such a way that one system developed on one microcomputer, such as the Apple Macintosh, will automatically work the same way on other microcomputers, such as IBM PCs and Unix workstations. Nexpert Object also allows the user to specify potential goals to be investigated as well as whatever initial information the user believes to be useful, taking advantage of the capabilities of Nexpert Object to perform both forward and backward chaining with the same rule structure.

Efforts are being made to match as closely as possible the sequence of prompts offered by CUSHFIT. The prompts themselves, however, have been redesigned to take advantage of Nexpert Object's object-oriented nature and ability to display graphic images. For example, in the original version of CUSHFIT, the user would be prompted to provide skin conditions at several sites by typing the number corresponding to an item in a list (i.e., 1 for good condition, 3 for some redness present, etc.). CUSHFIT has been redesigned so that by using a mouse, the user can point to and click on a site of the human body, wait for the expert system to prompt for the skin condition at that site, and then click directly on the appropriate skin condition. In addition, the user at any time can query the expert system by clicking on a "Why?" button to discover what conclusion the expert system is currently investigating and what relevant information has already been established.

DISCUSSION

Thus far, CUSHFIT has been redesigned to take advantage of modern expert system development tools. The improvements achieved include:

1. extension of decision-making procedures to include Boolean and backward chaining which increase the efficiency, flexibility, and speed of operation of the expert system;
2. improved facility for updating the program to accept new products, clinical scenarios, or clinical tools used in the decision-making process; and,
3. greater user friendliness especially with regard to the use of advances in the man-machine interface using icons and mouse-controlled input.

At this time, a prototype version of the redesigned CUSHFIT expert system has been developed and a critique from potential clinician users at UTREP and HHH is being obtained.

ACKNOWLEDGMENTS

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VISUAL SIGNALS PROJECT

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ABSTRACT

The Visual Signals Project was sponsored by the U. S. Architectural and Transportation Barriers Compliance Board (ATBCB) to characterize an effective fire alarm signal for hearing impaired persons. The principal research activity under this project was the testing of volunteers with hearing impairments to determine the human response times to different types of visual signals. As a result of testing, the research team was able to establish a proposed standard for visual alarm signals.

BACKGROUND

The Alarms Documentation Project (2) surveyed deaf persons, facilities managers and fire officials to determine perceptions of need on the part of the users of visual signals and to determine the kinds of alarms systems currently in use. The general consensus among deaf and hearing impaired users was that visual alarms were very desirable, especially in locations where people might be alone during a fire emergency. The project found a lack of experimental and experiential information about visual alarms' effectiveness and recommended to ATBCB that further research was needed to determine the effectiveness of visual signals as alarms for hearing impaired persons. This project was a result of that recommendation.

METHODS AND RESULTS

Testing was carried out in three phases. The first phase was to determine what combinations of color, intensity and flash rate were most effective, and which, if any, were ineffective. This phase was carried out under "laboratory" conditions to avoid uncontrolled variables and to minimize the number of subjects. The variables of intensity/color, and flash rate were tested. These variables had the following values:

Intensity / Color:

150 Watt Incandescent / Red
150 Watt Incandescent / Blue-green
150 Watt Incandescent / Yellow
150 Watt Incandescent / White
Low Intensity Strobe / Red
Low Intensity Strobe / Blue-green
Low Intensity Strobe / Yellow
Low Intensity Strobe / White
High Intensity Strobe / Red
High Intensity Strobe / Blue-green
High Intensity Strobe / Yellow
High Intensity Strobe / White

Flash Frequency:
One Third Hertz (one flash every three seconds)
One Hertz (one flash every second
Three Hertz (three flashes every second)

All possible combinations of the above variables were tested. Three combinations were found to perform significantly better than the others, and were carried into Phase Two testing. These were:

Incandescent / White, One Third Hertz
High Intensity Strobe / White, One Hertz
High Intensity Strobe / White, Three Hertz

In Phase Two testing, these three signals were tested in different placement combinations in a 1,000 square foot office with windows and in a sixty-foot corridor. The incandescent lamp was ineffective under these conditions. Both strobe lamps were effective, and a single alarm signal device was sufficient for the thousand square foot room. The effectiveness of the signals in a corridor began to fall off somewhere between 40 and 60 feet from behind a subject.

The third phase was a validation phase, wherein the two signals of choice (one and three Hz, white, high intensity strobe lamps) were tried out in actual offices in Manhattan. The research team had hoped to run 64 tests in 16 offices, but achieved only 43 tests in 14 offices. For both signals, the average time to alert under field conditions was less than ten seconds. The longest time was 42 seconds. In the absence of absolute criteria for an effective signal, this performance seemed to confirm the general effectiveness of both signals.

CONCLUSIONS

Visual signals with the following characteristics were found to be generally effective in alerting people with hearing impairments in a variety of office environments:

Type of light :	Xenon flash tube
Color of light:	white, or clear
Flash rate:	1 Hz - 3 Hz
Intensity:	min. 75 candela - seconds, max. 120 candela - seconds.
Flash Duration:	Approximately 1 millisecond

COST ANALYSIS

The research team performed a cost impact analysis to estimate the cost of providing visual signals in federal office buildings. Two typical buildings were modeled to compare costs of existing alarm systems with those of visual signals. A consideration of the level of coverage vs. cost led the research team to recommend the use of visual signals in all restrooms and other general usage areas where an employee is likely to be alone at any time, in hallways, lobbies and other common use areas, and in those offices and other use areas where a person with hearing impairments is an assigned occupant. This approach can be expected to raise alarm system costs by 8% to 50% over current alarm systems, depending on building design. This is a net impact of much less than one percent (0.06% to 0.12%) of total building cost. The lifetime cost per hearing impaired employee for full implementation can be roughly estimated to be about $4,000. It should be noted, however, that a visual alarm system would also alert employees with normal hearing when they operate noisy equipment or when, for any reason, they might not hear an audible signal.

DISCUSSION

The scope of this research was limited to visual signals in office-type environments, so these results should not be applied to dissimilar occupancies. Non-traditional geometries or room spaces should rely on NFPA 72G (8) for illuminance and placement standards. Nor should these results be applied to areas where people are likely to be sleeping. The effectiveness of visual signals in wakening sleeping persons is being addressed in parallel research funded by a grant from the National Institute for Disability and Rehabilitation Research (NIDRR) to the University of Massachusetts, Dr. Harris Nober, Principal Investigator . This project is scheduled for completion in 1989.

ACKNOWLEDGEMENTS

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DIRECTION DISCRIMINATING HEARING AID SYSTEM

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ABSTRACT

A visual display system has been developed for people with substantial hearing loss in one ear. The system has bidirectional microphone audio input and a visual display at the output indicating the direction from which sounds originate. The system is based on a custom developed CMOS integrated circuit.

INTRODUCTION

Individuals who suffer a severe hearing loss in one ear have great difficulty discerning the direction from which sounds originate. Situations may exist where such individuals must be made immediately aware of the origin of the sound particularly a loud sound. Typical examples include general street traffic, fire alarms, loading dock horns, sirens and a variety of less common audibles but of equal warning power.

METHOD

The basic approach to solving this problem is to detect sound from two directionally oriented microphones. The two signals are amplified and compared. The stronger signal is then visually displayed as volume light bars. The organization of the system is shown in Fig. 1. An audio signal is detected from each of two directional microphones positioned in opposing directions. The signal received from the microphone facing the audio source will be stronger than the signal from the other microphone. Both microphone signals are amplified and rectified. Each rectified dc signal is fed to a 3-bit analog to digital (A/D) converter. The two digital signals are then compared in a digital comparator. The digital comparator controls the transmission of the received signals. Only the stronger signal is transmitted through the enabling port. This signal then actuates a visual light-emitting diode (LED) bar graph display to indicate the relative volume of the sound.

The system has been designed with complementary MOS transistors. Fig. 2. shows the circuit diagram of the amplifier, the output of which is rectified with a diode peak detector. The amplification is controlled by the amount of negative feedback using an external potentiometer.

The 3-bit A/D converter consists of 8 comparators (Fig. 3) and a 8 × 3 encoder, (Fig. 4) connected as a flash A/D converter. Each comparator uses the same circuit as the operational amplifier. The encoder, as well as all other logic circuits, is also designed with CMOS.

The digital outputs from the A/D converters are compared using a digital comparator shown in Fig. 5. The output of the digital comparator is used to control (enable) the transmission of the 3-bit converted digital signal of the stronger channel through a logic unit, as shown in Fig. 6. This logic unit has seven outputs to drive a 7-bar LED bar graph.

IC DESIGN AND FABRICATION

The entire electrical system was subjected to a SPICE analysis (circuit simulation) and then converted to a single CMOS chip. The design, analysis and chip layout was performed at the University of Maryland and wafer fabrication was accomplished through the DARPA/NSF sponsored MOSIS program. Each chip contains over 900 transistors, resistors and capacitors. The chip size is 4555 × 6719 microns. A photomicrograph of the chip is shown in Fig. 7. A bread board model of the complete system including microphones, electronics and display was developed and successfully operated from a 3-volt battery supply. A second generation is currently under development where the entire system will be encased in a pair of eyeglasses and will ultimately be available to the general public.

ACKNOWLEDGEMENT

This work was sponsored by Mr. Don Friedman of the Office of Commercial Programs, as part of the NASA/GSFC Space Technology Transfer program.

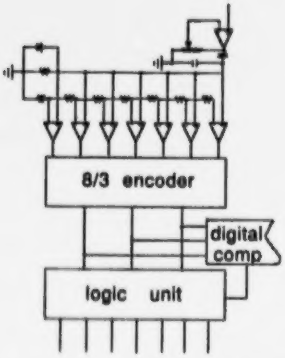
8/3 encoder
digital comp
logic unit

Figure 1. Block diagram of system.

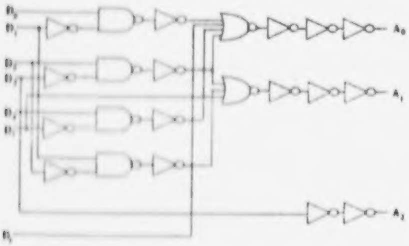

Figure 3. Circuit Diagram of Encoder.

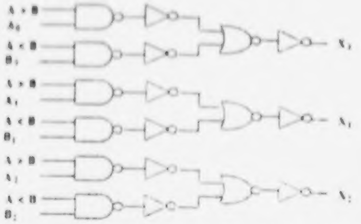

Figure 5. Circuit Diagram of Selection Logic.

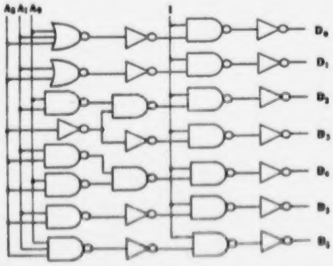
D₀
D₁
D₂
D₃
D₄
D₅
D₆

Figure 6. Circuit Diagram of Output Logic.

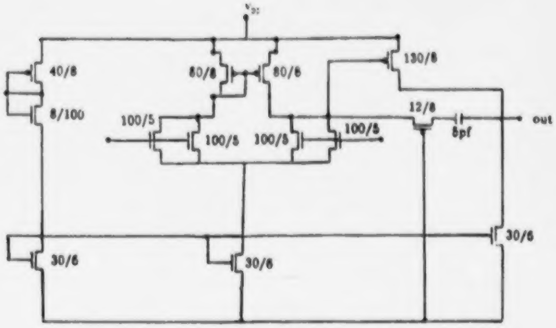
40/8
8/100
80/8
80/8
130/8
100/5
100/5
100/5
100/5
12/8
5pf
out
30/6
30/6
30/6

Figure 2. Circuit Diagram of Operational Amplifier.

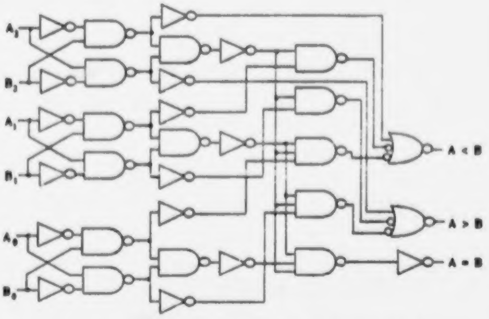
A₂
B₂
A₁
B₁
A₀
B₀
A < B
A > B
A = B

Figure 4. Circuit Diagram of Digital Comparator.

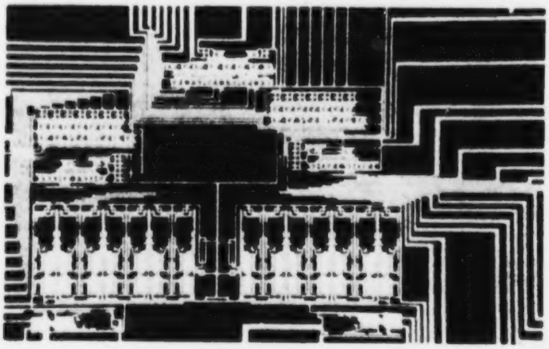

Figure 7. Photo micrograph of IC.

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BONE VIBRATOR PLACEMENT AND CANCELLATION

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ABSTRACT

Bone conduction represents an alternative mode of signal delivery for certain types of hearing aids. An issue in the measurement of bone conduction sensitivity is the placement of the bone vibrator. The effect of bone vibrator position on the amplitude and phase of the received signal was investigated. The results showed that forehead placement was advantageous in that the amplitude of the received signal did not vary significantly with vibrator position for placement close to the center of the forehead. In contrast, the phase of the received signal was critically dependent on vibrator position. Further, substantial intersubject differences were obtained in the variation of phase with bone vibrator position.

An important consideration in the use of bone conducted signals is placement of the bone vibrator. Studebaker (1), Weston, Gengel and Hirsh (2), and others, have recommended forehead bone vibrator placement over mastoid placement when measuring bone conduction thresholds for increased reliability and validity.

A key assumption underlying the recommendation of center-of-the-forehead placement for the bone vibrator is that uniformity of the frontal bone provides a wide surface area over which changes in threshold sensitivity are small. This assumption, however, has not been tested directly.

It is possible to measure both the amplitude and phase characteristics of bone conducted stimuli by means of a cancellation procedure (3, 4). This is done by cancelling the signal delivered by the bone vibrator with a signal delivered acoustically via an earphone that is equal in amplitude but opposite in phase.

The purpose of the present investigation was to examine the effects of systematic changes in bone vibrator placement across the forehead. Both the amplitude and phase characteristics of the bone conducted signals were of interest.

Nine placement points across the forehead were considered covering a range of 14.4 centimeters, with each point being 1.6 centimeters from its neighbors. The nine placement points were symmetrically located relative to the center of the head. Data were also obtained for the bone vibrator placed on the mastoid. In a second experiment, 21 placement points spaced 0.4 cm apart were considered. Three subjects participated in the first experiment. The follow-up experiment using much finer spacing was performed on only one subject. All subjects had hearing sensitivity within normal limits and no history of auditory pathology.

A method of adjustment was used for all cancellations. The subject controlled the amplitude and the phase of the signal presented to the test ear via air conduction. Initially, the bone conduction (reference) and air conduction (test) signals were presented separately and thresholds were determined. The signals were then presented at a sensation level of 30 dB. A check was made with the subject to ensure equal loudness between the two signals before beginning the cancellation measurements. The signals were then presented simultaneously and the phase of the test signal was adjusted until a loudness minimum was reached. The amplitude of the test tone was then adjusted until a second minimum was reached. The phase and amplitude of the test tone were then adjusted in finer increments until the tone was no longer audible and cancellation was achieved.

The results of the investigation indicate that forehead placement is not a critical factor with regard to the amplitude of bone conducted stimuli. The standard deviation of the amplitude measurements was found to be on the order of 3 dB for all three subjects. Except for a near-ear effect for two subjects, there was no significant variation in the amplitude of the bone conduction signals as a function of vibrator placement. Placement at the vibrator on the mastoid resulted in a significantly higher signal amplitude. Placement at an extreme position of the forehead close to the test ear resulted in a slightly higher amplitude (the "near-ear" effect).

In contrast, the phase of the bone conducted signal was highly dependent on bone vibrator position. The phase vs position curves varied substantially with frequency. There were also large inter-subject differences.

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COMPRESSION AMPLIFICATION BY INDIVIDUALIZED ADJUSTMENT OF CONSONANT-VOWEL RATIO

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ABSTRACT

Increasing the intensity of consonantal sounds relative to that of the adjacent vowels (the consonant-vowel ratio) has been found to improve consonant identification for hearing-impaired listeners. This improvement has been measured for various consonant classes. The largest improvements were obtained for consonants having significant amounts of frication.

The primary aim of compression amplification is to reduce the dynamic range of the speech signal so as to match the dynamic range of the impaired auditory system. Much of the research in this area has focussed on syllabic compression although the results obtained thus far do not show a consistent pattern of superior performance for this form of compression (1).

A form of syllabic compression that has received relatively little attention is that of adjusting the consonant-vowel (CV) ratio so that the weaker consonants are closer to the vowels in average intensity. This form of signal processing may be viewed as phonetically-based compression amplification in that the gain of the system is adjusted for specific sound types. Experimental evaluations of this form of processing have yielded promising results. Gordon-Salant (2, 3) obtained significant improvements in speech recognition for a 10 dB increase in CV-ratio. Montgomery and Edge (4) also obtained a significant improvement in speech recognition, at a signal of 65 dB SPL, but unlike Gordon-Salant, they did not obtain a significant improvement at high signal levels (95 dB SPL). Montgomery and Edge, however, used higher CV-ratios than Gordon-Salant and consonant levels may have been too high at 95 dB SPL. Further, they observed significant inter-subject differences and two of their ten subjects showed improved performance at the higher signal level. The above experiments indicate that adjustment of the CV-ratio can improve speech recognition for hearing-impaired persons, but that research is needed to determine the optimum CV-ratio and how it can be adjusted effectively for individual subjects.

An experiment has been performed in order to determine the effect of changing CV-ratio on the identification of various consonant types. A set of vowel-consonant nonsense syllables was stored digitally in a PC-AT computer fitted with analog-to-digital and digital-to-analog converters (12 bit quantization, 20,000 Hz sampling rate for an operating bandwidth of 10,000 Hz). The consonant portion of each nonsense syllable was excised and amplified by a multiplicative constant k. This multiplicative constant defined the relative adjustment to the CV-ratio. For k = 1, the adjustment to the CV-ratio was 0 dB; for k = 2, the adjustment was +6 dB; for k = 4, the adjustment was +12 dB. Pilot data have been obtained on two hearing-impaired subjects in which the CV-ratio was adjusted over the range 0 to 12 dB for each of the major consonants in English in a set of vowel-consonant nonsense syllables.

The largest improvements were obtained for voiceless stops, the gain in percent correct identifications increasing from 60 to 90 percent on the average. Significant improvements were also obtained for the fricative consonants (both voiced and voiceless). Increasing the CV-ratio showed no improvement with strongly voiced consonants. For the nasal consonants, an increase in the CV-ratio produced a reduction in performance. In addition to the differences in the relative improvements obtained for the various consonant classes, significant differences were also obtained between subjects.

Averaged over all consonants, an improvement of roughly 15 percentage points was obtained. This result is consistent with the findings of Montgomery and Edge (4) and Gordon-Salant (2, 3). Applying the same gain in CV-ratio to all consonants, however, reduces the advantages of this form of compression since different CV-ratios are optimum for different consonant classes.

The results of this study suggest that a phonetically based compression system in which gain is increased when frication is present (as occurs in fricatives and voiceless stops) might prove useful. In an earlier investigation (5), an experimental hearing aid using an algorithm of this type was found to be useful with profoundly hearing-impaired children. This device both amplified the fricative components of speech and also reduced their average frequency. This same approach, using amplification only for the fricative components, appears promising for moderate to severe hearing impairments.

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TECHNOLOGY TASK FORCE FOR PERSONS WHO ARE DEAF-BLIND

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ABSTRACT

The technological needs of persons who are deaf-blind are not being adequately met. As a result of this, a task force was organized by a group of service providers, technology professionals, and persons who are deaf-blind to promote the adaptation of existing technology and the development of new technology for persons who are deaf-blind.

INTRODUCTION

The population of persons who are deaf-blind is very heterogeneous. Some persons with deaf-blindness are professionals: conversely, some live in institutions for the profoundly retarded. Persons who are deaf-blind also differ from each other based on their degrees of vision and hearing loss, age of onset, which disability occurred first, language development (none to sign language or English competence), and communication mode (braille, fingerspelling, sign, speech, and print). Due to the complexity of their disabilities, it is very difficult to define the needs relative to technology for persons who are deaf-blind. Also, due to the low incidence of deaf-blindness, and the fact that many persons who are deaf-blind are also isolated and may even be unknown to service providers, no one organization or group can speak in behalf of or about the entire population of persons who are deaf-blind. Therefore, a group was organized to promote the development of the technology that has been somewhat neglected but desperately needed by persons who are deaf-blind and to provide an interface among persons who are deaf-blind, service providers, and technology professionals.

BACKGROUND

A group of 20 persons involved with or interested in technology for persons who are deaf-blind, including service providers, technology professionals, parents of deaf-blind children, and persons who are deaf-blind met on January 25, 1989, at Gallaudet University, Washington, D.C. The participants represented 14 different organizations, several of which are national leaders in deaf-blindness, service provision, and technology.

INITIAL MEETING

The initial meeting served as an introduction to the Task Force. The group "brainstormed" ideas about the Task Force and its possible activities. Discussion about specific ideas and technologies also occurred. The agenda included:

a) a discussion about the purpose of the Task Force and the needs relative to technology of persons who are deaf-blind.
b) several short presentations of new technology to stimulate discussion.
c) a discussion about possible activities of the Task Force.

The next meeting was scheduled for May 5, 1989, and an agenda was outlined.

Definition of group and interaction process

The purpose, objectives, and functions of the Task Force need to be further defined. After determining priorities, the group needs to survey the needs relative to technology of persons who are deaf-blind, and examine the appropriateness of current technologies, considering the feasibility of adapting them.

Possible areas of inquiry

Although most technologies for persons who are deaf-blind are based on tactile codes (usually braille), the reasons that many persons who are deaf-blind have difficulty learning these codes has not been determined. These kinds of issues may need to be examined before more action is taken.

Possible activities

Lists of appropriate technologies that are available or that could be easily adapted need to be developed. Appropriate devices should be made available at convenient locations so that persons who are deaf-blind can try them out. Other possible activities are:

a) a meeting of persons who are deaf-blind to define their needs.
b) a conference for educators of children who are deaf-blind to inform the educators about technology used by adults who are deaf-blind which can also be used by children.

c) a working conference of technology professionals to consider specific technologies.

WRITTEN SURVEY OF PARTICIPANTS

Defining the needs relative to technology of persons who are deaf-blind is a major concern in the field and a prime objective of the Task Force. The group was requested to send in written ideas about these needs. A summary of the needs generated by the Task Force will be mailed to the participants and further discussion will occur at the next meeting.

The needs relative to technology of persons who are deaf-blind should be categorized into domains such as communication, education, Orientation and Mobility, independent living, work, and recreation/leisure. The needs relative to technology of the entire population of persons with deaf-blindness, which consists of children and adults with low and high intelligence, and those who live in foreign countries, should be included in the discussion of any one type or domain of technology.

DISCUSSION

All the individuals involved with the Task Force agree that the needs relative to technology of persons who are deaf-blind are not currently being met in a cohesive fashion. There are a number of individuals or groups working alone, but there is a need for an organized forum for sharing information about current technological advances, as well as defining the needs relative to technology of persons who are deaf-blind.

ACKNOWLEDGEMENTS

The National Information Center on Deaf-Blindness is coordinating the Task Force. Dr. H.T. Prickett is the moderator. Gallaudet University provided the facility and interpreters. Personal expenses of participants were paid by the organizations they represented.

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TECHSPEC: A TECHNOLOGY TRAINING MODEL

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ABSTRACT

In order to increase knowledge of rehabilitation and assistive technologies among graduates and professionals, the Trace Center and Occupational Therapy program at the University of Wisconsin-Madison have instituted a preservice training program called TechSpec. The program offers two levels of specialization, and will create disseminable materials for other programs.

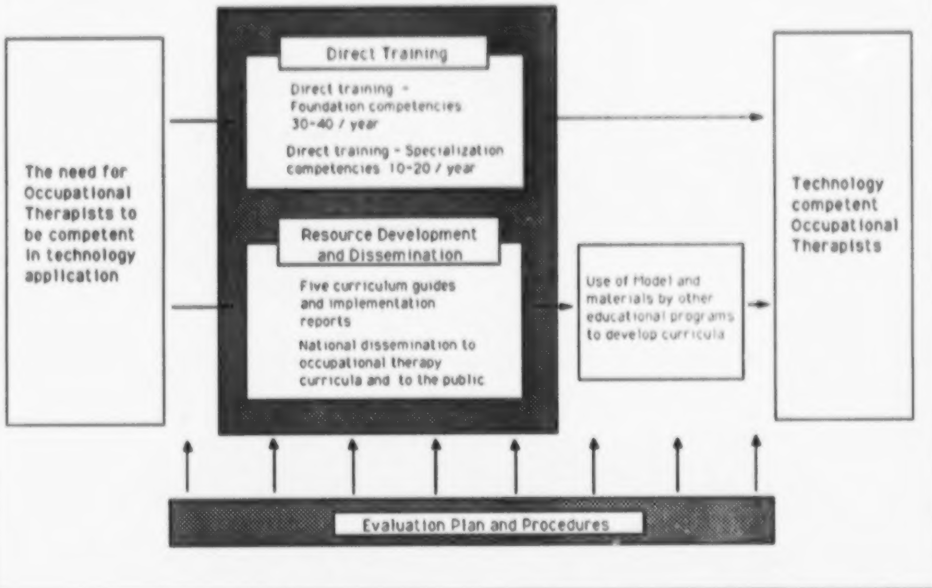
Any review of RESNA-sponsored training activities reveals that technology education has been acknowledged by RESNA as a critical need. One focus area of technology education is preservice training in clinical disciplines. Clinicians must be increasingly aware of the potentials of technology in clinical application. Occupational therapists, for example, should, in the course of their training, be exposed to the full range of technology applications, including many topics covered by RESNA Special Interest Groups. Furthermore, educational curricula are needed which go beyond foundation training and begin to provide the basis for specialists who can work on technology teams.

Unfortunately, clinical professional training curricula encounter substantial barriers in incorporating technology coursework in their already packed and usually lock-stepped classroom, laboratory, and field work studies. Four common barriers to technology training in occupational therapy professional programs include:

1) Insufficient teaching materials available,
2) Insufficient models on which to base a technology program aimed toward occupational therapy students,
3) Insufficient technological program equipment and supplies, and
4) Insufficient practicum placements.

Fortunately, there are key institutions which have substantial technology resources. In the past, these resources have primarily focused on basic research, research and development, information dissemination, technology transfer, and clinical demonstration. Preservice and inservice training, until recently, however, had usually been conceptually considered as needing separate types of funding. Consequently, there had been a historical division between research centers with rich resources in the area of rehabilitation technology and training programs aimed at producing technologists for working in service delivery settings. Over the past decade in occupational therapy, an increased mandate to include better technology training has evolved.

Figure 1
TECHNOLOGY SPECIALIZATION (TechSpec) DESIGN


The need for Occupational Therapists to be competent in technology application
Direct Training
Direct training - Foundation competencies 30-40 / year
Direct training - Specialization competencies 10-20 / year
Resource Development and Dissemination
Five curriculum guides and implementation reports
National dissemination to occupational therapy curricula and to the public
Use of Model and materials by other educational programs to develop curricula
Technology competent Occupational Therapists
Evaluation Plan and Procedures

TECHSPEC: A TECHNOLOGY TRAINING MODEL

At the University of Wisconsin-Madison, it became apparent several years ago that many regional, national, and international resources were available on campus, but that there was no mechanism for occupational therapy students to formally tap the resources available. A significant training potential existed, with the resources of the Rehabilitation Engineering Center at the Trace Center and the University Hospitals and Clinics' Communication Aids and Systems Clinic, Rehabilitation Engineering Department, and Neuromuscular Retraining Center, along with strong Occupational Therapy and Health Systems/Human Factors Engineering academic departments. However, no program yet existed. Consequently, in 1988 a formal attempt to coordinate these resources was made, with an initial focus on occupational therapy students. This curriculum, now entering its second year, is supported by funds from the Division of Personnel Preparation and NIDRR of the U.S. Department of Education.

THE TECHSPEC PROGRAM

Acknowledging that technology training needs exist both on the University of Wisconsin-Madison campus and throughout the country, the TechSpec program was developed with two major thrusts (see Figure 1). The first thrust is direct training; the second, the development and distribution of training materials.

Direct Training

Direct training consists of two tracks: some students receive foundation level training only, while others are trained to a specialization level. Students who choose to participate in the foundation level of the program select elective technology-related courses. Some courses have existed for many years; others have been developed specifically for the TechSpec program. The competencies targeted for the foundation level training include:

1) Graduates should understand technology as applied in rehabilitation and education. They should be aware of its history, potential, general constructs and applications.
2) Graduates should be familiar and comfortable with using technology.
3) Graduates should know where resources exist, and use them appropriately.

Students enrolled at the specialization level in the TechSpec program complete a specified set of courses plus electives. Required courses include: a survey course; three basic clinical courses; design, adaptive and construction courses; and practicum courses. These total 23-27 credits, of which 12 are already occupational therapy professional requirements. An additional 3 credits of elective study in technology-related coursework rounds out the curriculum. Courses approved for electives include coursework in Physics, Mechanical Engineering, Industrial Engineering, Educational Technology, Computer Sciences, Communication Disorders, and the School of Allied Health Professions. Upon completion of the classroom, laboratory and practicum instruction, TechSpec specialization graduates qualify for a certificate in technology specialization. Targeted competencies for the technology specialists include:

1) Graduates should be familiar with a core set of technological systems and their applications.
2) Graduates should be able to assess a person's skills and deficit areas related to technology application.
3) Graduates should be able to match technological applications with the individual's particular skills and deficits to increase their functional abilities.
4) Graduates should be able to train children and young adults to use appropriate technologies.
5) Graduates should understand and apply the benefits of interdisciplinary teaming.

Resource Development and Dissemination

In addition to producing occupational therapists with specialized training in technology, the TechSpec program is producing teaching workbooks and an implementation manual for the Madison TechSpec model. These resources are being made available at cost to other faculty, curriculum planners, and the public.

TECHSPEC PROGRESS

Within the first year, 62 students have participated in TechSpec courses. The majority of students have been from the Occupational Therapy professional training program; however, Industrial Engineering, Physical Therapy, Education, and Family Resources students have also taken these courses. Additionally, eight occupational therapy postgraduates have enrolled. Fourteen occupational therapy junior and senior students have been formally admitted to the TechSpec program, with eight seniors targeted to graduate following the first year of the program. These initial enrollments surpass the expectations and plans of the TechSpec design. Modest increases over the next three years are anticipated. Involvement of students from other campuses and other disciplines is being encouraged. A full program evaluation is underway, with data confirming the important need for technology training and the initial success of this particular program.

It seems clear that one way of ensuring the success of technology training programs is to associate the programs with existing technology resources. It is the responsibility of settings with research and development, service delivery, technology transfer, or information dissemination resources to consider technology education programs. It also seems apparent that settings without technology resources should consider methods of obtaining better technology resources or accessing programs which may have them. Finally, it seems that it would be best for both settings with resources and settings without resources to coordinate in order to optimize a technology training system.

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PUBLIC AND PRIVATE RESOURCES: DISCOVERING AN OPEN EAR TO IMPLEMENTING SERVICES

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INTRODUCTION

In the state fiscal arena, hospital funding, including third party reimbursement, provides only part of the means for rehabilitation technology service development. As a result, persuit of alternative avenues for supporting a service delivery system becomes essential. Educating others in the scope and need for rehabilitation technology services requires time and patience in one's schedule to allow for presentations and other public relations efforts. Without having one's own development staff, service providers must find a balance between direct service and program expansion. This paper outlines a "plan of attack" that has brought much support to an established program for rehabilitation technology services.

FOUNDATIONS AND CORPORATE CONTRIBUTIONS

Available to certain qualifying public services, foundations and corporate sectors become a viable resource for project seed money, equipment and various operating expenses. Members of our project team devote considerable time to establish program goals and justify the role of each contributing team member. Proposal preparation has been a time consuming effort from cover letters to the final dollar sign on the budget. While there has never been a guarantee of obtaining such monies, knowledge of local support groups and agencies has been most helpful. There has generally been two staff members that stay abreast of philantropic groups and potential funding sources through journals and other publications that target monies available for particular populations our project serves. What remains significant is that all potential resources are explored via letter or direct by phone inquiry.

UNIVERSITY AFFILIATIONS

In the past year, various universities and technical institutions have responded enthusiastically to the opportunity to become involved with undergraduate affiliations covering a variety of projects in rehabilitation engineering. Faculty at these universities had varied familiarity with areas of application, through the most popular responses were for development of devices for adaptive recreation, mobility and computer access. It is important to note that undergraduate student projects are not part of regularly provided services, but provide an educational setting and opportunity for undergraduate study. The student/patients that are often subjects for these projects understand that participation is voluntary. The benefits of a university affiliation have been:

1. Undergraduate exposure to rehabilitation technology.
2. University faculty has been a valued resource for consultation.
3. Some undergraduates have sought further experiences in this field through part-time work or volunteering with our programs. Since September, 1988 the following undergraduate projects have been undertaken:

1. a gear-reduction system for sports wheelchair
2. page turning device
3. skating chair
4. audio compass
5. hiking chair
6. canoe/kayak modifications
7. adaptive rowing apparatus

More that 20 undergraduate engineering students have participated in these projects.

VOLUNTEER STAFF

The community housing our facility, along with neighboring communities, has taken considerable interest in this program through our communication in public interest articles and brochures. Volunteers with backgrounds in carpentry, engineering and design have frequently been part of production staff. Others have assisted in public relations for the coordinating of university affiliations.

CONCLUSION

These resources have given a great deal of viability to a much needed service to residential students and persons with disabilities living in many communities. Taking the time to educate the public has been essential. Moreover, the presentation *of a cost-effective solution to providing equipment and services has assisted this effort. This approach has set the stage for wider range of services and has consistently provided a means for further dialogue and opportunity for additional funding.*

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AN ENGINEERING DESIGN COURSE USING REHABILITATION PROJECTS

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ABSTRACT

We describe a senior biomedical engineering design course that includes student-client interaction with handicapped children and their therapists. This appears to enhance the instructional process and faculty effectiveness.

INTRODUCTION

Engineering design is a difficult topic to teach in an undergraduate engineering program because of the need to deal with the multitude of differing aspects and unknowns of open ended problems. Design is not an exact body of knowledge, but a procedure that requires the systematic application of a decision making process that combines basic knowledge, craftsmanship, and common sense tempered by experience.

The student is often bewildered because this is far different from the closed form problems that have been the mainstay of his prior training. By working on projects that are challenging, yet feasible, and that have an immediate, understandable, and useful function, the student can experience the entire design process in action and can develop many of the necessary skills in a structured way. Many devices that aid the handicapped have the advantage of being simple enough to be completed by under-graduate students in a reasonable time, yet require careful consider-ation of utility, safety, esthet-ics, and a study of the needs and limitations of the end user. We describe preliminary observations of the inclusion of such projects in an engineering design program.

PROGRAM STRUCTURE

About one third of our graduating class of 40-50 seniors will continue on to medical school, a third will go to graduate or other professional school, and the rest will enter the workforce or military. They receive four years of instruction in an ABET accredited program terminating in a Bachelor of Science in Biomedical Engineering.

Our senior requirements include a year-long, 8 credit hour capstone design course that focuses almost entirely on applied problems related to engineering design. These are presented by lecture, required reading, and invited guests. The applications portion includes both individual and team projects.

INDIVIDUAL DESIGN PROJECTS

Every student must complete an individual design project. The level of effort required is 8 to 10 hours per week for the entire two-semester course sequence. Each student picks a project proposed and advised by a member of the academic, scientific, or professional community. The projects are usually a part of the ongoing research or professional efforts of these advisors. The use of outside advisors greatly expands the amount of individual attention received by the students. Students present the results of their design project in Departmental seminar and the final report as their Senior Thesis.

TEAM DESIGN PROJECTS

In-class team design projects require the immediate application of design skills as well as provide experience in project planning and administration. Students submit Gantt charts and other progress reports on a regular schedule. A final project report is required in which the student evaluates the design and the physical prototype that is constructed. A public show of the prototypes is a long-standing part of this process, and a Departmental tradition. Presenting the projects to the public heightens enthusiasm, increases awareness of purpose, enhances aesthetic appreciation, and makes the evaluation more incisive and complete. These projects bring to the fore considerations of safety, reliability, utility, and cost. The team design project for 1988-1989 is to design and build a feeding device for a handicapped child.

REHABILITATION PROJECTS

In 1987 we first solicited projects from therapists at Children's Hospital in New Orleans. Over a dozen projects were submitted and included in the project pool. These projects usually have specific clients, and the product is to be given to the participating client or family. Procedures for obtaining patient participation and for releasing the final prototype have been approved by the Institutional Review Boards of both Tulane University and Children's Hospital.

Examples of projects that have been delivered to clients include a home weighing device for a quadriplegic, a feeding machine, and a motorized tricycle.

PROGRAM SUPPORT

In addition to the regular engineering program, these projects are supported by: 1) A school supported machine shop that gives undergraduate projects priority; 2) Support for materials and supplies from the National Science Foundation; and 3) Children's Hospital. Children's provides a pool of clients and, for students selecting a rehabilitative project, training and health tests for registering as a Volunteer.

RESULTS

Several of the projects have been featured in the internal publications of both Tulane and Children's and on both local and national (CNN) television. This adds to both public awareness and to student perception of their design accomplishment.

Having monetary support for these projects (up to $500 per project) has opened great opportunities in building viable prototypes. Problems, however, include the tremendous amount of instructor time and effort required just for ordering, receiving, and distributing parts and materials. Not all of this can be left for staff to administer because the budgets are limited and material selection is part of the design process.

In addition to the design experience, the students have expressed an enthusiasm for "real" projects and have demonstrated an increased awareness and understanding of the problems of handicapped individuals.

CONCLUSION

The course presents design in a number of ways that sum to a well-rounded set of ideas, and culminates with hands-on experience under the guidance of seasoned professionals. Working with these individuals, the student learns how to put ideas into practice, participates in meaningful research and design, and learns the proper attitudes and approaches for dealing with disadvantaged individuals.

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REHABILITATION ENGINEERING TECHNOLOGY TRAINING: A CONSUMER DRIVEN, INTERDISCIPLINARY APPROACH

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ABSTRACT

Nearly two years ago San Francisco State University began a new RSA-sponsored post-baccalaureate training program for engineers and rehabilitation counselors in Rehabilitation Engineering Technology. We offer the following progress report to bring others who may be either contemplating or involved in the development of such a program a description and analysis of our experiences sofar.

PROGRAM PHILOSOPHY

A consumer driven approach is central to our program. For over 30 years disabled advocates, governmental agencies, and the private sector have struggled with the problems of putting assistive technology into the hands of disabled people. During this time there have been significant improvements both in available technology and in the service provision programs at both the national and regional levels. Yet, most disabled people still live their lives well below their maximum potential performance levels. We anticipate that a consumer driven approach will help to correct this shortcoming.

This program reflects its consumer driven approach in two ways. First, students interact throughout the program with a wide variety of disabled consumers and professionals. Second, students learn a service delivery model in which the professional acts as a consultant to the consumer who is in charge of the service delivery process.

The program consciously rejects the medical model of service delivery in which the professional is responsible for solving a "patient's" problem. Not only is the medical model less empowering to the consumer; its results have frequently been unsuccessful. When the decision maker does not have to live with the technology, choices are often made that do not fit the disabled person's environment, lifestyle or preferences.

It is only through comfortable, respectful and aware relationships with disabled persons that engineers and counselors are likely to contribute effectively to the improvement of assistive technology. A significant percentage of the students, Community Advisory Committee members, university faculty, guest lecturers, and consultants who have been chosen for the program have disabilities or have immediate family members with disabilities. In collaborating with and learning from them, students are encouraged to confront their own uncomfortable feelings about disabilities.

WE ARE LOOKING
FOR A FEW GOOD
ENGINEERS..

CURRICULUM

The curriculum was developed by an interdisciplinary team including the authors and Chris Schulenberger, Rehabilitation Engineer.

Interdisciplinary Approach: Engineers and rehabilitation counselors take the four core courses together. Professionals, who are expected to cooperate in the real world, gain experience working together in this program. Course content is interdisciplinary. All students are exposed to faculty from several disciplines. Several courses are team-taught by faculty from different disciplines. Students work on projects in cross disciplinary teams.

Problem Solving: Problem solving in assistive technology has never been easy. The highly individual problems faced by ech person with a disability can require intense creativity. The enhancement of creativity and problem solving skills is a major thread running through the entire program. Skills in these areas are taught to all students.

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Graduate Certificate in R.E.T: The graduate certificate program allows practicing professionals in both engineering and counseling to acquire expertise in the area of assistive technology. The curriculum also dovetails with M.S. programs in rehabilitation counseling and engineering. Classes are held in late afternoon and evening to accomodate working professionals.

CORE COURSES

Rehabilitation Technology Engineering I: A broad overview of assistive technology. A written case-study approach is used with field investigations to provide students with an understanding of the trade-offs involved in the selection of assistive technology.

Rehabilitation Technology Engineering II: Focuses on the development of skills that rehab engineers and counselors require; the emphasis is on serving as a resource to disabled people who are trying to remove complex barriers to independent living. Counselor-engineer teams work with experienced disabled people and their families to find new solutions to stubborn problems.

Medical and Social Aspects of Rehabilitation Counseling; Health Requirements for Independent Living: A two semester sequence which investigates medical aspects of disabilities. Interventions and coping mechanisms for use by people with disabilities are described. Practical experience is gained in architectural barrier assessment and in the medical evaluation of disabling conditions.

Internship in Assistive Technology: The Rehabilitation Engineering Center (REC) at Childrens Hospital at Stanford is a major participant in this project. Students observe and gain experience with the team approach to assistive tech service delivery used at this REC. Other field sites, such as the Disabled Childrens Computer Group in Berkeley, provide experience in the wide range of service delivery activities.

ADDITIONAL COURSE REQUIRED FOR COUNSELORS: Microcomputer Use by People with Physical Limitations - This course covers the selection of hardware and software and their use by people with disabilities.

ADDITIONAL COURSE REQUIRED FOR ENGINEERS: Advanced Design - The Human Interface - Problem solving, design methodology and ergonomics applied to the design of assistive technology. Emphasis is placed giving students and faculty, through personal experience, a better understanding of how to cope with new disabilities and how to function while using adaptive equipment. A major design project is required.

WHAT'S GOOD?

The program has fulfilled many of its goals. Student quality is generally quite high based on instructor and field site supervisors evaluations. Engineering students have designed a number of products which have commercial potential. Employment opportunities for certificate holders seem very promising. The program is attracting numerous inquiries regarding the certificate. Engineering and Counseling faculty involved in the program have learned to work in an interdisciplinary and cooperative manner. And most importantly, we are delivering on our promises of providing an exciting and innovative consumer-driven assistive tech program.

WHAT COULD BE BETTER?

Several issues and challenges have surfaced which are relevant to others setting out to develop similar programs. The integration and acceptance of a new interdisciplinary program into conventional university departmental structures has been difficult. Faculty from different departments and different professional "cultures" have needed to learn to work together. The integration of service professionals from the field into a teaching environment enriches the program. However the use of professionals without teaching experience requires the teaching faculty to oversee and facilitate the professionals' teaching.

The role of the rehabilitation counselor in the assistive technology delivery system is not yet well defined; working toward that definition presents an ongoing challenge in our program. We get requests for advanced training from people working in the field who do not fall into the categories of engineer or rehab counselor; we are looking for ways to accomodate them. Finally, given the political nature of the provision of assistive technology services, faculty have been required to spend considerable time working in the community to affect policy regarding assistive technology service delivery.

RECRUITMENT

We are still recruiting engineering students. Applications for the Fall semester will be accepted through June. Only five engineering students are admitted each year. Financial support is available.

This project is funded under a grant from the RSA. For more information, contact:

RET Training Project
SFSU School of Education
1600 Holloway
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TECHNOLOGY FOR DEAF AND HARD OF HEARING STUDENTS

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I. INTRODUCTION

This paper describes assistive devices and instructional technologies and, to a lesser extent, technological services and building adaptations which will make colleges and universities more accessible to deaf and hard of hearing students. Deaf and hard of hearing students require technological adaptations in order to have access to the full range of information and signals available to other college students. Hard of hearing students benefit from equipment which amplifies sound and from building adaptations which reduce noise. Both deaf and hard of hearing students benefit from equipment which delivers information and signals visually and from building adaptations which reduce visual distraction.

II. ASSISTIVE DEVICES

A. TELEPHONES/TELECOMMUNICATIONS

1. A TDD (telecommunication device for the deaf also referred to as TTY) is a device which has a keyboard to type messages, a printer and/or screen to read messages and a coupler which connects the TDD to a telephone so that deaf people can use the public telephone system. A TDD can be built into a payphone or can be provided as a separate portable unit. TDD calls into an institution can be facilitated by a dedicated TDD line. TDDs are an established technology with a network of small business distributors.

2. Phone amplifiers boost telephone receiver volume. Amplifiers exist for payphones and for personal telephones. Telephone amplifiers are available from telephone companies and assistive device distributors.

3. Hearing aid-compatible public telephones are mandated by federal law.

4. Telecommunications such as electronic mail and bulletin boards provide information in a visual format using a modem-equipped computer or an ASCII-equipped TDD. Electronic mail systems such as Specialnet, Deaftec and Compuserve have special features for disabled people.

5. A TDD modem allows a computer to send or receive calls from TDDs or computers.

B. ALERTING DEVICES monitor smoke detectors, telephones, doorbells and other equipment. They set off a flashing light or tactile signal when the smoke detector or other equipment has been activated. Alerting devices are portable or hardwired and are available from assistive device distributors. Some portable alerting systems have campus-wide communication links through pagers that have vibrating capability which alerts the device-wearer. (Large-scale visual safety alarm systems are also described in Sec. III, Building Adaptations.)

C. ASSISTIVE LISTENING DEVICES OR SYSTEMS (ALDs) are used to amplify sound in one-to-one conversations, in meeting rooms, lecture halls, and in assembly halls. ALDs used in group settings include: induction loop, FM and infrared systems. ALDs are routinely used with public address systems in large assembly areas. ALDs are portable but some can be permanently installed. ALDs are available from ALD manufacturers and distributors who may also provide on site assessments.

D. REAL-TIME SPEECH TO PRINT SYSTEM is a computer-based system for converting continuous speech (e.g. lectures) into print in real-time. This system employs a stenotypist to code and enter spoken language into a small input device in phonetic shorthand, which is then transliterated into print by a computer for near instant display on a television screen, or for printing as hard copy. The student receives the hard copy for class notes.

E. TELEVISION TECHNOLOGY

1. The television caption decoder (also referred to as an adapter) decodes closed caption signals which then appear on the TV screen in text form so that the viewer can read the television dialogue. TV decoders are portable and available through assistive device distributors.

2. Captioned videotapes are shown on a television monitor using a VCR if open captioned and a VCR and television decoder if closed captioned. Captioned videotapes may substitute for non-captioned videotapes or serve as additional video resources. Captioned videotapes are available in video outlet stores and from educational and audiovisual distributors especially those which serve deaf and hard of hearing people.

3. Instructional Technology includes the following:

- overhead projectors
- computer-assisted instruction with or without video
- computerized electronic mail and bulletin boards
- computer software packages identified as appropriate for deaf and hard of hearing students
- captioned films and videotapes
- VCRs
- television caption decoders

III. BUILDING ADAPTATIONS: THE OPTOACOUSTIC ENVIRONMENT[1]

A. INSTALLATION OF PERMANENT SPECIAL COMMUNICATION DEVICES

1. Fire alarm and smoke detector systems that activate strobe lights, vibrators and/or variable-velocity fans.

2. Graphic messages confirming receipt of emergency signals, such as a sign in an elevator flashing "help is on the way" when a malfunction is reported.
3. Visible signals on security alarms.

4. Pungent scent added to natural gas supplies in science laboratories and other locations to warn deaf persons unable to hear the hiss of escaping gas.

5. Warning lights that flash on when machines are running, or that signal when a machine has completed its task.

6. TDDs and telephone amplifiers on payphones.

B. PROVISION OF APPROPRIATE LIGHTING

1. Natural light as major light source.

2. Controls for room lighting in a location accessible to lecturer.

3. Glare control through blinds and other devices.

C. REDUCTION OF BACKGROUND NOISE AND INTERFERENCE

1. Educational sites in low-noise locations.

2. Insulating materials on or around equipment, ducts, etc. and silencers on fans to control mechanical noise.

3. Anti-static carpets to reduce electrical interference.
4. Avoidance of ultra-high frequency-sound security systems and low-cycle/electrical transformers, both of which can cause problems with hearing aids.

D. IMPROVEMENT IN THE ACOUSTIC ENVIRONMENT

1. Floor carpeting and sound-absorbing ceiling and wall materials in order to control sound reverberation.

2. Wall and floor insulation to prevent sound transmission.

E. VISUAL ENVIRONMENT

1. Semicircular seating and swivel chairs in large rooms so that deaf people can see the instructor and each other.

2. Round or oval tables for groups discussions.

3. Limited visual distractions.

4. Signage which provides directional information at prominent locations.

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[1] Most of the information in this Gallaudet College, "Breaking Through The section was extrapolated from Deafness Barrier."

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ACHIEVING ACCESSIBILITY: SECTION 508 AS CATALYST

Susan A. Brummel
General Services Administration

As part of the reauthorization of the Rehabilitation Act of 1973, a new section was added on electronic equipment accessibility. Section 508 requires Federal agencies to comply with electronic equipment accessibility guidelines in order to ensure that individuals with disabilities can use the information technology purchased or leased by the Federal government. An overview of agency and industry progress on Section 508 will be presented, together with discussion of the critical role that rehabilitation engineers and related professionals can play in advancing the implementation of this new and important policy.

The Federal Government has begun implementation of an important new policy that is likely to have significant impact on the roles and opportunities of rehabilitation engineers as shapers of flexible information tools to support individuals with disabilities.

Like other information-based settings, the Federal Government has been benefitting from rapid advances in information technology that have greatly expanded the number of tools in use by Federal agencies. Accommodating the functional limitations of users with vision, hearing, and mobility impairments would appear readily achievable in such an environment. Two major obstacles, however, have until recently threatened achievement of this goal: 1) poor utilization of off-the-shelf solutions currently available due to limited awareness, and 2) the possibility that technological advancements could outstrip the ability to continue to provide viable access solutions. To avert such a development, and in response to a Congressional mandate, GSA recently promulgated an accessibility policy for all Federal departments and agencies in its Federal Information Resources Management Regulation (FIRMR). This policy implements Pub.L. 99-506, Section 508 (29 USC 794d) regarding electronic office equipment accessibility. The policy states in part that: "Federal agencies shall provide handicapped and non-handicapped employees equivalent access to electronic office equipment to the extent such needs are determined by the agency in accordance with 201-30.007 and the required accessibility can be provided by industry. In providing equivalent access to electronic office equipment, agencies shall consider:

1) Access to and use of the same data bases and application programs by handicapped and non-handicapped employees;
2) Utilization of enhancement capabilities for manipulating data (ie., special peripherals) to attain equivalent end-results by handicapped and non-handicapped employees; and
3) Access to and use of equivalent communications capabilities by handicapped and non-handicapped employees."

The policy also outlines management responsibilities and functional specifications for equipment to assist agencies in achieving accessibility for their employees. As implementation proceeds, it is anticipated that accessibility-related equipment and support services will become integral aspects of agency acquisitions. Users with disabilities will receive equivalent equipment, training, and technical support as users without disabilities. In addition, however, users with disabilities will receive accommodation-related software and hardware add-ons as necessary, as well as additional training to use these enhancement products.

This policy acknowledges the necessity for acquisition planning that incorporates the special requirements of individuals with disabilities. Agencies are responsible to conduct a thorough assessment for determination of need and then include the necessary functionality as minimum requirements in solicitation documents. The responsibility then shifts to industry to outline a plan to meet agency requirements for accessibility when responding to agency requests for proposals.

Rehabilitation engineers and related professionals have several critical roles to play as implementation of this policy proceeds both within and beyond the Government. It is vital that agencies and other organizations know how to conduct effective assessments of employee needs and document the needs in a clear and functional manner. Similarly, industry needs the functional analysis and technical skills of rehabilitation engineers to conduct performance testing of their current system configurations and anticipate and plan for next generation requirements.

In addition, it is anticipated that as end user needs evolve, the acquisition plans of Federal agencies will increasingly reflect the total information processing environment of all individual end users. The assessment tools developed to determine accommodation needs for individuals with disabilities could be applied to determine an optimal interface for users without disabilities. Accommodation in the broadest sense refers to the application of ergonomic principles to maximize the capabilities of all users. The assessment skills of rehabilitation engineers could thus contribute to advancing the overall flexibility of the user interface.

Experience is beginning to show that when acquisition planning includes the special needs of users with disabilities cost-effective, integrated, accommodation solutions to access problems are achieved that in many cases also serve as a catalyst to the introduction of well-designed technology innovations of benefit to all users.

As we expand the environments and circumstances in which we want to utilize information resources - noisy or mobile environments, space, and hands-busy, eyes-busy environments, we begin to recognize that by providing the flexible alternatives or enhancements to our standard I/O devices - monitor and keyboard for users with disabilities, we're also solving functional use limitations of non-standard working environments.

Agency experiences with accommodation solutions that incorporate emerging technologies (ie., speech synthesis and recognition) provide an effective means for evaluating future applications with potential benefit to all end users. Although speech output is used primarily by visually impaired users today, it is anticipated that many more users may rely on this capability in the future. The same screen reading capability that currently supports the auditory review of display information by an individual physically unable to review a visual display because of sight limitations will in the near future support effective remote telephone access to a variety of information. In the future, agencies may employ telephone management systems with a speech synthesis interface to handle many routine, but time-sensitive inquiries. A caller could select from a choice of messages by selecting the appropriate touch-tone button or voice-activated code, including the option to talk to an operator/ information specialist.

The same speech input system that supports information/data entry by a user physically unable to use a keyboard can support a quality assurance inspector looking at integrated circuit chips under a magnifying glass where use of only a keyboard and monitor would be very fatiguing and inefficient.

Access now as a matter of course will provide user flexibility as a matter of necessity in the non-standard information workplace of the future and ensure that the needs of all users are met.

In conclusion, we are finally recognizing the significant productivity and human resource benefits that can accrue to government, industry, and individuals with disabilities when standard information technology can be readily enhanced to support all users. New management policies for accessibility are speeding the introduction of flexible hardware platforms and innovative computer/telecommunications functions (speech recognition, text-to-speech, information service terminals, and electronic text, voice, and fax mail) that benefit and accommodate the requirements of users with disabilities. These innovative users, in turn, have the opportunity to facilitate agency adoption of emerging information products and services of benefit to all users.

There remains much work to be done and many opportunities for rehabilitation engineers and related professionals to usher in a new age of universal accessibility to information resources.

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NEW YORK STATE TECHNOLOGY RESOURCES INFORMATION NETWORK

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INTRODUCTION

The first recommendation of the 1987 New York State Governor's Task Force on Technologies and the Disabled is:

"The State of New York develop a fully integrated and interactive central information system to provide for retrieval, dissemination and exchange of information in the areas of disability and disability technology."

Funding from the US Department of Education established the New York State (NYS) Technology Information Network. This Network represents a collaborative effort of NYS public and private agencies, corporations and consumers.

INFORMATION NETWORK AS MODEL

The Technology Information Network was developed to operate on two levels: (1) function for the end users within New York State; (2) serve as a model for adoption by other states. The system's design in terms of both process and structure, is driven by the constraints and opportunities present in the environment. By working with the state's environment as is, under the assumption that conditions are generally representative of the conditions in all states, the network will be robust and generalizable.

A major problem confronting an individual with a disability is the lack of access to available information on special devices, and adaptations to existing devices that could increase their functional independence. Service providers/professionals face the same difficulty in accessing this information. Access to this information should be centralized to facilitate state-wide dissemination. Fortunately, centralization of access does not mean that all information must be stored in one central location. With this in mind, the NYS Technology Information Network was designed to have one point of contact for all consumers state-wide, while leaving most data resident at the point of origin.

An attempt to create and maintain a central database representing all known information would be resource prohibitive. Further, the resulting database would be continually outdated. Both factors precluded use of a central data repository as a transferrable model. Therefore, the network was designated to provide comprehensive and current information by communicating in real-time, directly with the information source.

Generating extraordinary support for the network (i.e., special funding or unusual efforts to gather data) was not considered feasible because such support cannot be sustained. Relying on extraordinary measures jeopardizes the network's long-term viability in New York State and its' feasibility for export as a model. Therefore, the information network was designed to stem from ordinary levels of resources and routine data accessibility, using a minimum of dedicated staff time.

Recognizing that there is great disparity in technological capabilities for communication among agencies and individuals, and that implementing a sophisticated interactive network would require the purchase or acquisition of new equipment by all participants, the information network was developed to use technology already in use by potential participants. Consumers only need a telephone, while participating agencies have minimal communications technologies.

Previous Experience

Vanderheiden's experience in Wisconsin suggested that a three-tiered semi-centralized network is optimal for the purposes described. Such a system permits central coordination, provides regional centers with responsibility for identifying information sources, and allows local resource centers to fulfill their mission. It also provides users with a central point of contact, delegates staffing responsibility to the most effective levels which reduces the need for new personnel, and the model can be implemented through low-level technology. It enables local resource agencies to share their equipment and expertise in a timely manner. Further, all levels of the system participate directly in service provision, encouraging continued interaction via the network.

COMPONENTS

Central Resource Center

The Central Resource component of the system is in Albany, the State capital. The central location is staffed full-time. One toll-free voice and one (TDD) telephone number distributed state-wide, services all calls about technology resources from anyone in the State.

The Albany Center serves as a clearinghouse for in-coming inquiries. It has directories listing where in the state -- and secondarily outside the state -- information on a specific topic can be found. Each inquiry is routed to an appropriate Regional Center. Thus, the Albany Center is responsible for connecting an inquiry with a response, and for tracking the status of each inquiry. In most cases, Albany does not supply specific answers to inquiries. The Albany Center also functions as the interface point for information networks outside New York State. These connections give New York residents access to virtually any information available in the nation. The Albany Center has access to five databases maintained at the University at Buffalo Data Center: (1) Company listings; (2) Government agency resources;(3) Educational Opportunities;(4) Consultant/Educator Registry; (5) Listings and brief descriptions of Local and Regional Centers.

Regional Resource Centers

Twelve locations in New York State are designated as Regional Resource Centers. All Regional Centers were selected from agencies already staffed and equipped to serve the public. The Regional Resource Centers interact with local components and the public in a network system, as modeled by the Planning Committee Network. Regional centers interact with local resource centers to remain current on technological information and assistance available throughout the region. In a manner similar to the Central Resource Center, the Regional Resource Centers act as clearinghouses for the local resource centers in their region. To this end, Regional Centers maintain directories of all information currently available through their Local Resource Centers. The Regional Centers either serve as, or are developing, product demonstration centers for the public. These regional centers interact with the public to disseminate information compiled through the system, and to direct consumers to the appropriate local resource center.

Local Resource Centers

Local resource centers are where the bulk of the technologies, information and expertise actually reside. The information network simply coordinates information and directs the public to appropriate local centers. The local centers share their capabilities with the public as a natural extension of their missions. This expectation must be met for an agency to be designated a local center. The additional obligation on the agency's part is to update the appropriate Regional Resource Centers on changes in local information and capabilities. Timely updating enables the Regional Resource Centers to keep their resource directories current. Any inquiries that cannot be handled satisfactorily at the Regional or Local levels are directed back to Albany for additional referral, either within or outside the NYS Technology Resources Information Network.

MODEL FOR INTERAGENCY COORDINATION OF TECHNOLOGY RESOURCES

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Center for Therapeutic Applications of Technology

INTRODUCTION

This project, initiated October 1, 1988, is funded by the US Department of Education to *improve cooperative interagency activities among State and local educational agencies having potential to provide statewide or interstate access to and use of technology to meet the early intervention, educational, vocational, and transitional needs of individuals with handicaps* (1988). This project also responds to the recommendations of the New York State Governor's Task Force on Technologies and Disabilities, whose charge was to examine *how new and developing forms of assistive technology can be better applied, and made available to those New Yorkers who need it* (1987).

The goal of this project is to facilitate access to technology devices for individuals who have disabilities. To accomplish this, the project will:

(1) establish a process for planning technology utilization in New York;

(2) develop a comprehensive system that will enhance communication and cooperation among State, local, and private agencies;

(3) continue the work of the New York State Governors Task Force on Technologies and Disabilities, through accomplishment of tasks related to the recommendations in their Final Report.

Activities associated with the project are coordinated from two bases: one in Albany, the State capitol, and one in Buffalo, at the State University of New York at Buffalo. The New York State Office of the Advocate for the Disabled, which guided the work of the Task Force on Technologies and Disabilities and has been involved in other Technology related initiatives will assist in planning and carrying out project tasks.

To plan technology utilisation the Interagency Planning Council was established, with representatives from major state offices and departments, private agencies and organisations such as the United Cerebral Palsy Association; from industry, including IBM, Apple, Tandy, and AT&T, committees of the New York State Senate and Assembly; and consumer representation. The Council held its first meeting on October 31, 1988. The Planning Council meets 3 times each year to continue development and implementation of a plan for cooperation in service delivery for technology related devices for individuals with disabilities.

The system for enhanced communication and cooperation among State, local, and private agencies is being developed and implemented concurrently with the work of the Planning Council. The communication system will consist of (1) a quarterly newsletter on technology related issues, with contributions from all agencies; (2) "grass roots" regional conferences held around the state to include participation by local agencies (4 per year).(3) a New York State Technology Information Network, accessible via an 800 number (described in detail in a separate paper).

In carrying out the recommendations of the Governor's Task Force, efforts relate to problems with transportation, funding, access, consultation, education, and employment. In some cases participation in legislative efforts is necessary to meet the recommendations. In other cases agency level policies and procedures effect positive change in increasing service delivery in the area of technology devices for individuals with disabilities. The planning council is developing the strategies for carrying out the Task Force's recommendations.

This project has established a system for communication and cooperation among agencies within New York State. This system will also serve as a model for other states.

BACKGROUND

The opening paragraph of the report of the Governor's Task Force on Technologies and Disabilities summarises the problem addressed by this project:

One of the greatest opportunities that the advancement of technology offers to people with disabilities is improved independence and an increased standard of living. Through the assistance of a variety of existing and newly emerging technologies, persons with disabilities are able to undertake tasks which had previously been beyond their means. Being able to perform these tasks opens opportunities for gainful employment and personal fulfillment. The existence of special technology, however, does not guarantee its availability to those who need it.

The recommendations of the New York State Task Force are:

1. The State of New York develop a fully integrated and interactive central information system to provide for retrieval, dissemination and exchange of information in the areas of disability and disability technology.

2. The State act to enhance the incorporation of technology considerations and uniform criteria into the assessment process to determine needed services for individuals with disabilities.

3. The State Medical Assistance Program place greater emphasis on the availability of rehabilitation medicine on an outpatient, non-clinic oriented basis,... to assess individual needs and prescribe adaptive equipment.

4. The Department of Social Services Equipment Loan Fund be evaluated and modified to increase the cap on available loans and to tie interest rates to the individual's ability to pay.

5. The State Department of Transportation continue its efforts to develop and implement a statewide plan for accessible public transportation, and work closely with regional and local transportation service providers to integrate these services into a coordinated network.

6. The State legislatively require that insurers offering health and disability income insurance make coverage available for specialized medical equipment, procedures or services necessary for an individual with a disability to return to work or school.

7. The State should devise strategies for ensuring that training programs for professionals in the rehabilitation field include up-to-date information on rehabilitation technology.

8. The State create or assist in the creation of a series of product demonstration centers across the State. These centers would provide an environment for consumers and professionals to gain greater familiarity with available technology, and for product manufacturers to obtain valuable input on the needs of consumers and the degree to which their products meet those needs.

9. The State act to publicize the availability of rehabilitation technology through cable television and video production on selected topics, and through the development of a presentation on technology for exhibition at the State and County Fairs.

10. The State establish a program providing specialized training to New York based companies that produce special technology. Such training would focus on marketing concerns and other issues unique to the disability / technology area, and could be incorporated within existing State administered programs.

11. The State undertake a special effort to market its economic development programs to the disability technology industry. Few firms in this industry have applied or benefited from State programs in the past.

12. The State continue its support of Job Fairs that match employers who have job openings with individuals with disabilities who are seeking employment opportunities. These efforts should be expanded wherever possible.

13. The State Department of Labor expand its Annual Labor Area Report to include its current information on occupational shortages with job descriptions and worker requirements such as aptitudes, physical demands and environmental condition analysis, among other categories.

14. Develop a publication to promote increased consideration of workers with disabilities for various occupations among employers. Such a publication should identify recent technological advances and products which are "enablers" for disabled workers, cite specific occupations that people with disabilities can accomplish, and draw attention to workplace accommodation techniques.

15. The State create a low-interest fund to cover the purchase costs of adaptive technology and workplace accommodation.

16. The State promote the training of people with disabilities for employment opportunities through the publication of a report illustrating successful models of training and placement programs, improving communication between employers and training providers and including the Special Education structure in local partnerships between industry and the schools.

17. The State place increased emphasis on the use of Job Training Partnership Act monies for employment training of people with disabilities.

18. The State create a number of Rehabilitative Technology Centers which would conduct and oversee "needs driven" research on rehabilitation technology, provide education and outreach to consumers and researchers, and transfer developed technologies through commercialization by the private sector. State funding for these centers would provide the majority of operational support for several years, matched on a percentage basis with private support.

19. Create a Governor's Award for Technology and Disabilities, to promote recently developed technology with significant impact for people with disabilities, young researchers in high schools and colleges who show great promise as contributors to the field of rehabilitation engineering, among other categories.

The Governor's Task Force on Technologies and Disabilities initiated its work in February, 1987, and submitted its final report at the end of that year.

Comments are encouraged and can be addressed to:

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P1.1

THE ULTIMATE KEYBOARD EMULATOR: COMPUTABILITY'S AID+ME

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ABSTRACT

At this time there are many keyboard emulators on the market (1,2); however, clinicians, educators and consumers dream of the day the ultimate keyboard emulator is introduced. This device will have the ability to interface to a variety of computers, allow alternate input capabilities including electronic augmentative communication devices, run completely transparent to applications software, and have a price tag under $1000.00. The dreamers can stop fantasizing: AID+Me has these capabilities and more.

PHYSICAL CHARACTERISTICS

ComputAbility Corporation, 101 Route 46 East, Pine Brook, NJ 07058, (201) 882-0171 introduced AID+Me (Alternate Input Device + Mouse emulator), a keyboard emulator transparent to all software, in October 1988. Aid+Me, priced at $660.00 (February 1989) for one computer system, consists of a keyboard with serial input, interface box with built in speech synthesizer, and cables. The breakaway style keyboard, eight inches long by nineteen inches wide, has 101 keys in two colors and has a port for alternate keyboards on its cable. The interface box is eight inches in width, nine inches in depth, and two inches in height with a backlighted LCD display of 40 characters, each a 5X8 matrix with an additional 5X3 block below for down hanging characters, on the front. On the box's right side there are three female nine-pin ports (joystick, Power Pad, and mouse), LCD contrast knob, and keyboard reset button; speaker volume control knob, speaker jack, male nine-pin output port for Apple IIgs and Macintosh, male 15-pin output port for Apple IIe, and two switch jacks on the left side; and on the rear power: toggle switch, female 25-pin auxillary serial port, AC adapter jack, male nine-pin host serial port, male 34-pin AID+Me keyboard port, and five-pin DIN port for an IBM type keyboard.

SYSTEM FEATURES

As do other emulators, AID+Me interfaces to various input devices designed for special needs including alternate keyboards, expanded and contracted models, and switches for scanning. The interface box's LCD display provides the scanning line rather than placement on the monitor screen. Several commercially available input devices such as joysticks, Touch Window, and Power Pad may also be used to provide input. Mouse emulation is possible in three different modes, some of which allow the user selection of mouse, HeadMaster, or a variety of products including AID+Me Keyboard, alternate keyboards, Power Pad, Touch Window, and joystick. In addition there is support of an an ASCII serial mode which permits the interfacing of outside speech synthesizers and electronic augmentative communication devices, EvalPac and SpeechPac with RealVoice, TouchTalker, and Light Talker. With the appropriate cables and host system (Apple IIe and IIgs, Macintosh, IBM PC, AT, XT, PS2 and true compatibles) AID+Me supports OS/2, PC/MS DOS, DOS 3.3, ProDOS, and XENIX operating systems. For those desiring to run both Apple II and IBM software, but not wishing to purchase two systems, AID+Me, because of its transparency, has the capability of working with Trackstar 128, an IBM and true compatible add-on board (3,4).

CUSTOMIZATION CAPABILITIES

Much flexibility in customizing the device for individuals is available through the customization menu which is accessed by three keystrokes. Customizing capabilities include control of input device, auditory feedback, speech output, formation of 0-94 messages 1-50 characters long, rate, and repeating of keys. Keys may be redefined (messages will follow), more than one input mode may be used at a time, and customized overlays may be designed for the Touch Window, Power Pad, and alternate keyboards. A setup disk for the host system permits AID+Me startup menu redefinition, parameter selection, overlay creation and printing abilities, and file saving, printing, uploading and downloading capabilities. Individuals wishing to use the same AID+Me with a variety of computers may purchase appropriate cables and setup disks from ComputAbility.

AUGMENTATIVE COMMUNICATION DEVICE

Because the built in speech synthesizer is a standard feature of the product, AID+Me also has the capability of standing alone as a self contained augmentative communication device. This is a different approach than the norm of using an keyboard emulator to interface a communication device to a computer: the emulator itself is used as the communication device and is then attached to a computer when the running commercial software is desired. External battery packs are available from ComputAbility.

ACKNOWLEDGEMENTS

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P1.2

LIAISON by DU-IT:
Complete Utilization of Computers and Software by High Level SCI Quadriplegic People

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DU-IT Control Systems Group, Inc.

With LIAISON a high-level SCI quadriplegic independently operates all functions of computer and accessories. It presents a keyboard and other functions on a color monitor located beside the computer work screen. The operator uses his precision to point at display elements via a small movement proportional joystick. Keystrokes are entered using acceptance time criteria. 8-15 wpm rates are typical; memory features increase this. Designed for remote operation from DU-IT SCI wheelchair systems, LIAISON is also operable without the system. It has large macro capability, ECU functions, emulates mouse/joystick, and permits user layout of keyboards. Any software an able bodied person might use, the LIAISON user can operate. This paper presents the design criteria for LIAISON.

INTRODUCTION:

LIAISON is an alternative keyboard/emulator which allows a high-level SCI quadriplegic to independently operate all functions of a computer. It demands precision of the operator (usually in the form of x/y proportional positioning) and rewards him with convenient, fast typing. We designed LIAISON to address these major considerations:

1. Independent utilization within the routine of daily living.
2. Independent operation of all computer processes.
3. Easy operation of ancillary functions commonly needed while computing.
4. Operating rules that are self-apparent, easy and consistent.
5. Capability to operate software that anyone else might use.
6. A control process workable for quadriplegics from C-4 to C-1.
7. Keyboard and mouse emulations useable with many computers.
8. Compatibility with present and future DU-IT w/c systems.
9. A general device maleability under the user's control.

GENERAL COMMENTS:

We assess our independence in terms of constraints encountered during a particular effort. If we experience no other obstacles than the ones encountered by anyone else doing the same task, we perceive a relative independence. A person who becomes quadriplegic((SCI) wants to use a computer for much the same purposes as able bodied persons. The programs he needs to use, and the manner in which he wants to function entails tasks that are like those of anyone else. He wants to use his computer independently; he does not want to surrender other capabilities in order to attain this one.

DISCUSSION:

Independent Use and Daily Living

Since a person with high-level SCI has a scarcity of useful control signals, it is advantageous to use his most effective signals for multiple purposes. Directing these signals should be under his control so that he can independently determine what function he is controlling. LIAISON uses proportional position signals which it receives from a DU-IT wheelchair system. The solution to his mobility can become the solution to computer access. Once in his powered wheelchair, he is able go to his computer (as well as anywhere else) and use the computer without assistance. The DUIT system provides a "Go where you want to go; do what you want to do," atmosphere.

Independent Operation of Computer

Merely typing into a computer is not independent computer use. The computer, and other functions, may need to be turned on and off. Some programs need mouse, joystick, or tablet input. Special combination keystroke sequences may be needed. LIAISON provides a way to deal with these things conveniently. Speed of entry is also critical to practical application. LIAISON employs a direct selection, acceptance time, method of operation. Precision pointing is demanded of the user. Typing speed is the pay back. All appropriate users have achieved typing speeds of 8-15 wpm. In mouse mode, users can realizes performance comparable to those of able bodied persons.

Ancillary Functions

While using the computer, it is frequently necessary to use the phone or operate other appliance functions (X-10, page turner, tape recorder, etc.). The environmental control (ECU) capabilities of LIAISON reside within LIAISON and operate whether the computer is on or off. They include full function phone, 60 entry phone directory, 4 AC outlet groups on LIAISON, X-10 control (16), 3 control outlets, and video routing.

Use of All Software

Since LIAISON connects to the computer where the keyboard, mouse, etc. normally connect, its operation of the computer is identical to the usual input device. Everything that LIAISON accomplishes is done without any special programs running within the computer. The net result is general complete compatibility.

Useable by Highest Level Quads

Notice that only a proportional x/y signal is required for full utilization of all of LIAISON. (There is an additional simple switch needed in the DU-IT system). Strict adherence to this format assures that any who can operate a DU-IT SCI system will be able to control LIAISON. Even C-1 quads have been able to use the device effectively.

Different Computers

Within LIAISON's structure is a collection of keyboard engines. They determine how LIAISON will deal with the computer's keyboard input. By selecting a particular computer name in the "EMULATE" menu, LIAISON automatically produces keycodes needed to deal with various computers. This makes connecting to different computers an almost turn key process. Aside from these engines, LIAISON is always operating the same way.

Compatibility-Past, Present, Future

DU-IT is developing new wheelchair control systems. The control schemes and processes within LIAISON are designed to yield compatibility with the next generation systems as well as complete workability with any DU-IT SCI wheelchair systems made since 1976. This design criterion demands both an inexpensive telemetry format for our older analog system (timing not an engineering constraint) and provision for the new microprocessor system where some timing considerations are tremendously restrictive. All of this is already accomplished which assures compatibility with the next generation DU-IT systems.

User Alterable Adjustments/Features

There are many aspects LIAISON that should be tailored to the individual user. Some parameters such as acceptance time and deflection sensitivities may need to be altered daily. When limited to typing speeds similar to singlefinger rates, keyboard layouts tailored to particular tasks can greatly improve performance. Mental capability influences the balance between simple layouts and the greater power of more complex ones. LIAISON's tool box lets the user address these issues conveniently. The tools include:

1. Lay out your own keyboards
2. Draw your own keys
3. Lay out game boards
4. Adjust parameters pertinent to typing performance.
5. Adjust parameters pertinent to mouse, tablet, joystick.
6. Change keyboard emulation.
7. Manage memory processes.
8. Label ECU functions.
9. Handle telephone directory

CONCLUSION

Many units are in use by high-level quads. Learning to use LIAISON has been rapid for all users (1-3 hours). Learning to use some computer software and disk operating systems has been a much slower process.

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THE COMPUTER EVALUATION AND LEARNING LAB

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ABSTRACT

The Computer Evaluation and Learning Lab (CELL) program at the Palo Alto Veteran's Administration Spinal Cord Injury Center (PAVA/SCIC) began development in August, 1988, and is now serving as an assessment and training site in adapted computer technology for patients with spinal cord injuries. The program is based in part on a needs assessment completed with the patients and staff of the SCIC and complements other programs and resources in the service area. The lab is staffed by an adaptive computer technology specialist, an occupational therapist, and a therapy intern. A computer access evaluation tool and protocol have been developed. A research design to measure the effectiveness of computer intervention in terms of educational and vocational outcomes is in development.

INTRODUCTION

The SCI population is primarily made of young males who, due to medical advances, live a normal lifespan. The functional levels of these individuals can vary from complete dependence in all upper extremity activities to complete independence. Most depend on wheelchairs for mobility, some are ambulatory with or without adaptive aids. Recent advances in technology make access to computers affordable and physically possible for any spinal cord injured patient, regardless of the level of injury. Access to computers may be as basic a need for the patient with a spinal cord injury as access to the physical environment. With the ability to use a computer, the possibility of meaningful activity, control of the environment, and productive employment is available to individuals with spinal cord injuries.

The goal of the Computer Evaluation and Learning Lab (CELL) is to provide evaluation and training in the use of major computer systems and their applications to the patients of the Palo Alto VA Spinal Cord Injury Center (PAVA/SCIC). The training is specific to the individual's level of disability and life goals. Located in the Spinal Cord Injury Center, CELL is a project supported by funds from and Independent Living Grant with staff support from the Home Care Program and the Robotics Project.

BACKGROUND

In 1981, a study was done by Tang, et. al. at the PAVA/SCIC which found the use of an interactive computer learning lab to be meaningful and interesting to SCI patients (1). However, a formal training program was not implemented at this time. In 1987, computer hardware and software were purchased with funds from an Independent Living Grant to be used in the comprehensive rehabilitation of the patients at the PAVA/ SCIC. However, no formal service delivery program amd limited staff development was included with the equipment. One Macintosh computer was used in the therapy clinic to provide patients with an informal introduction to computer use as both a treatment modality and for diversional activity. Formal computer evaluation and training programs were beginning to develop in other hospital and community settings, but little data existed on the functional outcomes of these training programs with spinal cord injured patients (2,3). In June, 1988 a half-time position in the Home Care program was allocated to begin a more formal program and determine it's potential impact on functional outcomes for the participants.

METHODS AND MATERIALS

A needs assessment measuring the experience with and attitudes of SCI individuals towards computers was completed with the inpatients, outpatients and staff of the PAVA/SCIC. Results showed a high level of interest but limited experience and training in adaptive computer technology and its applications. Other VA and community programs were contacted to assist in defining the role of the CELL project in terms of effective delivery of services to the target SCI population. Based on these contacts, CELL was developed.

An integral componenet of CELL is the provision of comprehensive computer access evaluations. Evaluations are completed by an adaptive computer technology specialist and an occupational therapist on an individually scheduled basis. These evaluations include: review of patient medical history, diagnosis, and psychosocial status; motor, visual-perceptual, and cognitive functioning; environmental access (furniture, height of tables, space clearance), computer needs (applications software) and computer access (keyboarding skills, hand function, adaptive software and hardware). In the computer access evaluation, patients are asked to use a variety of adaptive software and computer control interfaces. These include a standard keyboard and mouse, trackballs, joysticks, switches, optical pointers, ultrasonic headpointers, and voice recognition systems. Speed, reliability, and consistency are recorded for each input device. Based on this evalution, specifications for individual computer systems and referrals to community programs/resources are made. Recommendations are based on the individual goals of the patient and complement other technology (chin control devices, wrist driven orthoses, environmental control systems) used by the patient.

Training content and methods are adapted from the curriculum used by the High Tech Center for Disabled Program (4). The High Tech Centers are funded through a grant from the state of California with the purpose of providing classes in accessing and using computer technology for disabled students in the community college setting. In applying this curriculum to CELL, structured courses are offered to each patient in word processing, graphics, and databases as appropriate. Instruction for special topics or for individuals with special needs are offered on an individual basis with content determined by the primary therapist and computer lab instructors. Courses involve homework assignments and group projects to be completed during lab time. The lab is open for assessments in the late morning and early afternoon, with free lab time in the late afternoon and early evening hours.

RESULTS

A multi-disciplinary task force was established in January, 1989 to assist in coordinating all computer-related activities at PAVA/SCIC. In February, 1989, space was allocated for the CELL project in the SCIC. An evaluation tool was developed. Assessments and limited training began in February, 1989. An initial needs assessment and a second, more focused needs assessment were completed to assist in program development. A grant proposal requesting additional staff, hardware and software adaptive devices, and maintenance funds was submitted to Paralyzed Veterans of America in March, 1989. Resource development is ongoing through contact with existing programs. A protocol has been submitted to establish CELL as an internship site for occupational therapy students specializing in adaptive technology.

DISCUSSION

The program goals were based on the results of the needs assessment. These results showed that patients and staff had limited experience with computers but were interested in receiving training, especially in the use of adaptive software and hardware which allow disabled individuals to access the computer. The preferred format for training was lecture plus hands-on use of computers for two to four hours per week. The most popular areas of interest for computer applications were in word processing, home management, graphics, and SCI education. Although most of the respondents were not aware of computer resources in their area, all were interested in receiving information on these resources. This suggested the need for a flexible, user-friendly database of computer resources, such as local computer stores, user groups, and community training programs to assist the novice user in maintaining computer literacy.

Assessment, training, and data base development have been limited by hardware availability, space availability, and staff expertise and availibilty. However, the CELL project has strong support from the physicians, staff, and computer task force.

Future work plans include increasing the number of patients served, addition of a voice recognition and new head control system, and establishment of patient projects, i.e., a newsletter and a community resource database. Evaluations one year post discharge will begin to study the effectiveness of the program.

CONCLUSIONS

The CELL project provides an opportunity to evaluate the effectiveness of a hospital-based adaptive computer program. The project is based on the hypothesis that the provision of computer access skills to the spinal cord injured patient as an integral component of a comprehensive rehabilitation program will improve the self-sufficiency of the individual with a spinal cord injury. Given specific evaluation, training, and education, the patients demonstrate specific functional behaviors which can be used to enhance the performance of daily life skills and tasks.

ACKNOWLEDGEMENTS

The work was supported by the SCIC patients and staff including Dr. Steve Linder and Irene Saperstein with funding by an Independent Living Grant through the Home Care Program, as well as Dr. Inder Perkash for providing space for this program in the PAVA/SCIC.

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DEXTER II - THE NEXT GENERATION MECHANICAL FINGERSPELLING HAND FOR DEAF-BLIND PERSONS

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ABSTRACT

Previous work by the author contributed to "Dexter", a computer-based pneumatically powered, electro-mechanical fingerspelling hand. It enabled deaf-blind users to receive tactile messages from the mechanical hand in response to keyboard input during person-to-person communication. However, Dexter's large size and power requirements were the prime motivations to producing a more compact and improved model - Dexter II.

INTRODUCTION

A common communication technique used with and among deaf-blind people is simply a hands-on version of fingerspelling. Instead of receiving communication visually as deaf people do, the deaf-blind person's hand(s) remain in contact with the hand(s) of the person who is fingerspelling a message, one letter at a time.

Such tactile reception has significant drawbacks. The first is shared by the deaf and deaf-blind populations: very few people are skilled in these manual communication systems. Consequently, there are very few people with whom to "talk." Using interpreters to help alleviate this problem presents still other problems such as locating, procuring, and paying for their service. A problem unique to the deaf-blind individual in need of hiring an interpreter is that many interpreters for the deaf, accustomed to being "read" visually, are not comfortable with the hands-on technique. In addition, the rapid fatigue resulting from this tactile transmission of information often requires the deaf-blind person to hire two interpreters so they can take breaks from continuous fingerspelling.

BACKGROUND

In an attempt to alleviate these problems, two previous mechanical fingerspelling hands have been developed. The SouthWest Research Institute (SWRI) in San Antonio, conceived and developed the first hand in 1977. This early device demonstrated the feasibility of transmitting linguistic information to deaf-blind people by typing messages on a keyboard connected to a mechanical hand. The hand formed the corresponding letters of the one-hand manual alphabet. This system was the first to enable deaf-blind people to receive communications not just from interpreters, but from anyone who could use a keyboard.

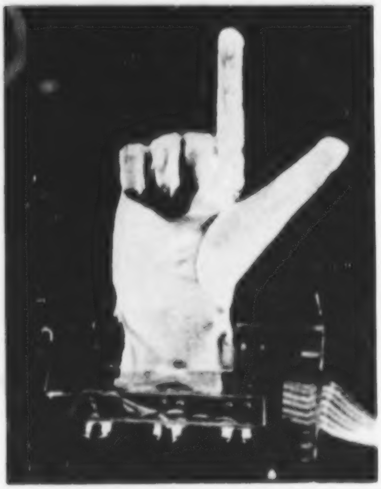
The first version of Dexter resembles a mechanical version of a rather large human hand projecting vertically out of a box. The four machined aluminum fingers and a thumb are joined together at a palm. All digits operate independently of each other and have a range of motion comparable to human fingers. The thumb is jointed so as to allow it to both sweep across the palm as well as move in a plane perpendicular to it.

Dexter was a successful substitute for a human interpreter. After a short practice session, deaf-blind users were able to understand the letters, words, and sentences it produced in response to messages typed on a keyboard. However, Dexter had its difficulties; its bulk and need for a supply of compressed gas severely limited its portability. Its custom machined parts made it a one-of-a-kind device - too expensive to ever be mass produced.

METHODS

A more compact version of the mechanical system has been designed in the Spring Quarter of 1988 by three graduate mechanical engineering students at Stanford University. Their design, Dexter II, employs DC servo motors controlled by pulse-width modulation. They rotate pulleys which cause individual drive cables, the "tendons" of the fingers, to be pulled. Torsion springs located in the "knuckles" provide a straightening force for unflexed fingers. Machined Delrin and aluminum stock make up the fingers and housing of Dexter II's smaller, re-styled hand. This design eliminates the bulky pneumatic power source used previously. A speed of about four letters per second (almost twice that of the first design) can be achieved with the improved device.

In operation, a message is typed on a keyboard (an Epson HX-20) by an able-bodied person. Each letter's ASCII value is interpreted by the control computer as a pointer into an array of stored control values. Two to six mechanical steps, each separated by a programmed pause, are needed to perform the finger movements corresponding to a single letter.



Dexter II

Although neither Dexter nor Dexter II can exactly mimic the human hand in fingerspelling all the letters (such as the special wrist and arm motions required in J and Z), they can display close variations (a dialect) which resemble them sufficiently to make them easy to learn by the deaf-blind user.

REHABILITATION
RESEARCH
AND
DEVELOPME
CENT

Dexter II and Dexter - Size Comparison

RESULTS

Dexter II was first tested by a deaf-blind person who is extremely proficient at receiving tactile fingerspelling. She provided many suggestions for improving its letter shape configurations. Subsequently, it was introduced to twelve deaf-blind people during their annual retreat. Their ability to initially understand Dexter II varied considerably, and long term evaluations have been planned.

DISCUSSION

In the next software design iteration, a finger position editing program will be written which will permit the interactive formation of letter-pair transitions. The data resulting from this phase will be incorporated into the next evaluation of Dexter II. The implementation of a full matrix of possible letter-pair transitions would eliminate the need for the "free-finger" neutral position and produce more fluid fingerspelling. A faster, more natural, and more intelligible fingerspelling device is anticipated.

Additional testing will be conducted to test the ability of deaf-blind people to use the Dexter II for extended periods of time, refinements of the letter configurations, and optimum rate of letter presentation.

CONCLUSIONS

Dexter II is intended to serve deaf-blind users as a complete receptive communication system, not just a means of receiving information in face-to-face situations. Its ability to respond to computer input permits it to be interfaced to a TDD to provide deaf-blind people with telephone communication. It can also be connected to computers to provide improved vocational and avocational potential to the deaf-blind community.

ACKNOWLEDGMENTS

Dexter II was funded by the Palo Alto Veterans Administration Rehabilitation Research and Development Center and developed at in conjunction with the Smart Products Design course and laboratory at Stanford University. Special thanks are due to the student team: David Fleming, Sheryl Horn, and Gregory Walker as well as Jim Anderson, the VA modelmaker.

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A Four Channel IBM PC/AT Compatible Biphasic Pulse Generator for Nerve Stimulation

P1.5

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ABSTRACT

An IBM PC/AT compatible four channel biphasic pulse generator has been developed to assist in functional electrical stimulation (FES) related research. Each channel uses a bipolar 12 bit digital-to-analog converter (DAC) to generate biphasic voltage pulses between +/- 5 VDC and three sixteen-bit timers to control first, second, and interphase durations. Two vectored interrupt generators are available for precise pulse timing control. Potential uses of this device include FES research, the characterization of the recruitment properties of percutaneous electrodes in multichannel stimulation systems, or as a sub-assembly in commercial medical devices requiring electrical stimulation in an IBM PC/AT platform.

INTRODUCTION

One of the most versatile and low cost platforms for computer aided research in recent years is the IBM PC/AT computer. Software and hardware systems abound by the thousands for this computer allowing researchers to avoid writing and laboriously debugging programs and to easily collect and analyze data immediately. This differs substantially from many traditional computer systems which required researchers to be adept programmers and custom hardware designers before they could perform their primary function as researchers.

Our laboratory has had several research studies over the years in which computer control of FES parameters was essential. These studies were performed on systems which are becoming expensive, difficult to maintain, and inflexible. Desiring to use our in-house IBM PC/AT's for present and future research, we sought a way to generate very precisely controlled multiple channel pulses for our neuromuscular stimulation studies. No appropriate commercial hardware for this function existed. The hardware and software system described here was developed as a low-cost and straight-forward development tool for data acquisition and analysis and stimulation parameter control for our research and for others.

SYSTEM OVERVIEW

The four-channel pulse generator consists of a six-layer printed circuit board designed to fit the IBM PC/AT computer. Requiring 64 bytes of I/O space, the board has a ten position DIP switch allowing the user to determine the board's base address. Up to sixteen boards could be accommodated in this manner (if expansions slots are available in the system bus), although with an increase in the number of channels. sacrifices would need to be made in maximal stimulation frequency.

Figure 1 depicts a block diagram of the pulse phase generators and timing controller for one channel. Phase and duration information for a complete FES pulse is preloaded into on-board registers. A write to a control register triggers a pulse. Both biphasic and monophasic pulses can be produced and each of the four channels can be independently operated.

The three timers depicted in Figure 1 reside in an Intel 8253 programmable timer integrated circuit. A single clock oscillator determines the counting frequency and may range from 2 MHz to 5 MHz depending on speed specifications of the 8253 parts purchased, resulting in a 200 to 500 nS phase duration resolution.

Two sets of latches for each channel store the first and second phase voltage levels. These 12-bit latches, under control of the programmable timer outputs, drive a bipolar 12-bit digital-to-analog converter (Analog Devices AD566). The output of each DAC is buffered with an operational amplifier (LM308), the output of which is brought to the rear chassis 25 pin connector along with a trigger signal generated by the timing circuitry.

A fifth Intel 8253 programmable timer is available to generate two interrupts to the IBM PC/AT CPU for accurate control of pulse trigger timing. One of the timers is used to generate a 1 mS interrupt for inter-channel timing and the second generates a 10 mS interrupt used for pulse-to-pulse timing on each channel. The 10 mS intervals form the smallest unit of inter-pulse-interval allowed, all other intervals being multiples of 10 mS. The 1 mS interval is assigned in sequence to each of the eight channels so that no channel overlaps another, however, the board is capable of simultaneous stimulation on all four channels.

On the IBM PC, there are no custom vectored interrupts because the CPU interrupt request and acknowledge signals are not available to devices not located on the system board. The designer of add-on circuitry must request a vectored interrupt mediated by one of the two Intel 8259 priority interrupt controllers on the IBM PC/AT system board.

The pulse generator board can generate four channels of voltage-controlled biphasic or monophasic pulses with voltages in the range of +/- 5 VDC, and phase durations from 0 to 65,536 clock periods, as the timers have 16-bit data registers. With a clock oscillator of 2 MHz, the upper limit is 65536 * 500 nS, or 32.768 mS; with a frequency of 5 MHz, the upper limit is 65536 * 200 nS, or 13.107 mS. An external voltage-to-current amplifier is used to take the voltage-controlled pulses generated on this board and convert them to constant-current stimulation pulses for delivery to the electrodes.

Stimulation timing

Stimulation pulse timing is controlled by the use of two programmable timer interrupts. The two timers described above can cause a single vectored interrupt to occur on the IBM PC/AT system bus. Polled hardware flags on the stimulator board indicate the source of the interrupt so that the controlling software can determine the source of the interrupt on the pulse generator board. In a system where multiple four-channel pulse generator boards are present, only one of the boards would be programmed to generate interrupts.

Each of the four channels are able to operate at any frequency, amplitude or phase duration. Because of this flexibility, great care must be exercised to ensure that when two or more channels are competing for a time slot in which to generate a pulse that there would never be any timing misalignments on any channel, resulting in an unwanted "jitter" in pulse timing, or worse, a missing pulse.

To achieve this jitter-free operation, the two sixteen bit timers are used to generate vectored interrupts at 10 mS and 1 mS intervals. The 10 mS intervals form the smallest unit of inter-pulse-interval allowed, all other intervals being multiples of 10 mS. The 1 mS interval is assigned in sequence to each of the four channels, starting after each 10 mS interrupt, such that each channel, whether or not it is producing a pulse in that 10 mS interval, is assigned a particular timing position relative to the 10 mS interrupt that never changes (see Figure 2.).

Expansion to eight or sixteen channels requires the addition of more pulse generator boards. If three boards were added to the system so that the total number of channels were sixteen, then the 10 mS interrupt would be changed to a 20 mS interval so that the maximum stimulation frequency would become 50 Hertz. Similar changes would be required if more channels were desired, up to the limit of 16 boards in a system.

Current implementation

Our laboratory is currently using one of the pulse generator boards in a system being developed for a study requiring four channels of modulated stimulation. An eight-channel voltage-to-current converter and amplifier is used to drive surface and implanted epimysial electrodes. This amplifier can generate monophasic pulses of up to 80 mA or 350 mA into inductively isolated monopolar or bipolar 1.5 KOhm electrode loads from the +/- 5VDC pulses generated by the board.

Stimulation parameter selection and control is similar to a system previously described [1] and involves the use of a graphics screen and entry device to generate data tables corresponding to the individual pulses generated by the board.

Software developed to support this board includes a small subroutine library which can be called with programs written in C, Fortran, Assembler, etc. Future plans are to develop a package of routines with enhanced functionality and with an interactive user interface.

DISCUSSION

The pulse generator board and its associated software has allowed us to integrate stimulation, data collection and analysis functions into a single development task for the IBM PC/AT. While our own laboratory has benefited from this device, other potential beneficiaries of the system described here include researchers interested in FES, researchers in neurophysiology, and clinical multichannel stimulation systems users requiring IBM PC/AT compatibility.

Interested parties are invited to contact the authors for information regarding the availability of the board.

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ACKNOWLEDGEMENT

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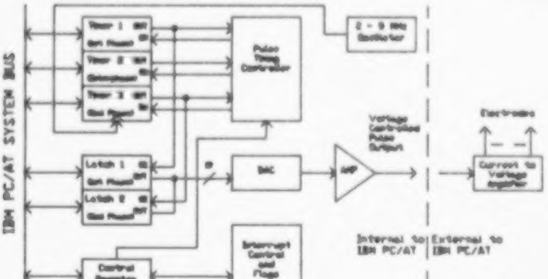

Figure 1.

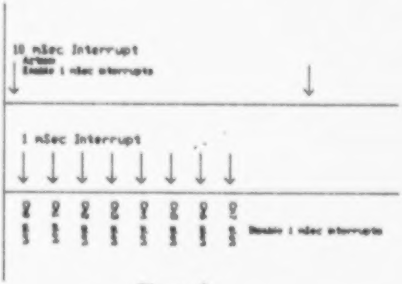

Figure 2.

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P1.6

CHAIRSIM: A POWER WHEELCHAIR SIMULATOR

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INTRODUCTION

For many patients, learning to drive a power wheelchair is a simple process. First, the patient is instructed in operating the chair. Then, under supervision, the patient begins driving. Finally, after several hours of practice, the patient confidently executes even the more subtle maneuvers. Learning to maneuver a wheelchair, however, is not a simple process for patients with severe physical or mental handicaps. Failure to issue the appropriate timely command can not only damage equipment and property, but also injure the patient and bystanders. Consequently, there is a substantial need for power wheelchair simulators.

BACKGROUND

Some wheelchair manufacturers provide the ability to simulate commands. For example, if a patient issues the command for a left turn then a left indicator may be lit. Generally, these devices are limited because they do not indicate the full effect of the command. A more desirable alternative is a real time simulator which demonstrates the effects of command timing and sequence.

DISCUSSION

The author developed a wheelchair simulator program called ChairSim. This program is used on computers in occupational and physical therapy departments. ChairSim runs on an IBM or IBM compatible machine equipped with a color monitor and a game port. The game port receives user commands either from a TASH joy-stick or a sip and puff module. ChairSim has several options. Option one helps the patient learn the basic power wheelchair commands. Option two displays a track upon the screen. Using the commands learned from option one, the patient must now maneuver an object around the track. For each unit of movement a distance score is incremented. Similarly, for each collision, a collision count is incremented. A very high collision count together with a low distance score are evidence that commands are either wrong or not timely.

RESULTS

ChairSim was tested on a handful of users. Though ChairSim was very helpful to patients, testing revealed some problems. First of all, some patients required auditory feedback each time a new command was issued or released. The patients said that they tended to rely on the clicking sounds of the relays within the power wheelchair to help them distinguish between hard puff, soft puff and no puff. As a result, optional sound was added to ChairSim. Also, because the track is circular, as the object made its transition from up to down, users easily became disoriented and lost track of what was left and right. It helped the users to imagine themselves sitting in the center of the object. However, a better solution would be to have the track always come down from the top of the screen and move randomly from side to side.

CONCLUSIONS

Finally, the author is working to overcome the problems mentioned above. Several standard tracks, an interface to allow for user designed tracks, adjustable speed and turning rates, and track obstacles are among the variety of new options being developed. ChairSim should prove to be a useful and flexible learning tool for inexperienced power wheelchair users.

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Special thanks to the Rehabilitation Engineering and the Occupational Therapy Departments at the Shepherd Spinal Center.

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P1.7

CONTROL OF DEVICES IN THE HOME BY DISABLED PERSONS: HUMAN FACTORS GUIDELINES AND PUBLIC ACCESS PROTOCOL

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ABSTRACT

Described are two approaches to allow people with disabilities the ability to control their environment and to allow them to live more independently. The first is a set of human factors design guidelines to allow the product developer to meet the needs of disabled people. The second is the development of a two-way electronic communication protocol which will allow many devices to be controlled from one central user interface. This user interface may be one currently being used by the resident (e. g. a touch talker) or it may be one specially produced. The communication protocol between device and interface will be distributed free to device manufacturers who will incorporate it in their products.

INTRODUCTION

This paper is an interim report on work being done by a group of volunteers who are studying the needs of individuals with disabilities. For the past two years the team has been interested in applying controls technology, human factors engineering, and artificial intelligence to the design of augmentative devices for persons with disabilities.

We are particularly interested in providing access to all devices and controls in the home. Our philosophy regarding the special needs of disabled persons is based on the following problem definition:

- Persons need convenient and economical access to all important controls and devices in their homes;
- Manufacturers of appliances and other devices do not understand the special needs of disabled persons;
- Highly specialized user interfaces have low volume and high cost;
- Most of these specialized user interface devices do not have the ability to communicate with and control common devices in the home.

In response to these problems we have taken on two projects to assist persons with disabilities in reaching the goal of control over their home and work environments.

HUMAN FACTORS GUIDELINES

Our first approach involves the specification of a set of human factors guidelines that provide design options for products that can be used by persons with disabilities. The guidelines are cross-referenced for specific types of disabilities. The broad categories are hearing impairment, visual impairment, motion impairment, mental impairment, and speech impairment. The guidelines employ, as design constraints, data regarding mobility, strength of extremities, and ability to see, hear, read, etc. These guidelines are based on data from literature reviews, demographic analyses, and interviews and performance data from subjects with disabilities. When completed, they will be distributed to manufacturers of appliances and other devices used in the home.

Although we believe that the guideline approach will be helpful, there is danger in specifying design recommendations, and then waiting for manufacturers to implement them. Design guidelines are, after all, only recommendations.

Moreover, human factors guidelines, no matter how informative and precise, are an adjunct to product development, and do not guarantee that useful products will follow. In the case of people with severe disabilities, they may never be helped by a human factors guideline document if the highly specialized interface they need is never built. Our second approach, the public access protocol, addresses this problem.

TWO-WAY COMMUNICATION PROTOCOL

Our second project involves the development and specification of a communication protocol which allows people to control almost any device in the home via their current user interface (i.e., a touch talker). With one interface a person can control their heating and cooling, arm and disarm their security system, turn on and off their lights, change the channel and adjust the volume on their television or similar devices. Further, since the protocol is two-way, the user receives feedback about whether the command s/he issued was actually carried out.

The protocol defines bandwidth, message types, user requirements, and a set of interactions. As long as devices "understand" this protocol and can interpret the commands received, they can be controlled via one interface. The protocol will be implemented via a communication adapter. Adapters are placed on the interface device as well as on the device which is being controlled. The adapter decodes the messages sent into instructions that the device can understand.

The adapters can use any communication medium, including RS232, infrared, radio frequency, and Power Line Carrier (PLC). After the communication protocol is developed and tested, it will be offered free to any manufacturers who will incorporate it into their products. In addition, we have been in contact with several manufacturers to develop adapters that are compatible with the protocol for their products.

PROJECT STATUS

The human factors design guidelines have been drafted, but we plan a significant revision and review before distributing them. An important factor in this revision is the addition of specific design guidelines for each of our target disabled populations.

The team developing the Public Access Protocol has developed and demonstrated a two-way infrared hand-held controller that can be used for the control of lighting, security, and environmental functions. Further, we have demonstrated that this can be done very economically.

Additionally, based on the concept of the public access protocol, we have developed and demonstrated several user interface designs for people with visual impairments, mental impairments, paraplegia, and quadraplegia. These concepts are implemented both on custom-built interfaces and on an Apple Macintosh using Hypercard to simulate the use of various specialized user interfaces.

Finally, we have developed a test plan to validate the design concepts. In this plan, people with disabilities will use installed prototypes of our system in their homes for a period of time. These prototypes will possess some subset of the total functionality. This strategy will serve to determine the ease of operation of our proposed products and the degree to which this type of product is helpful. The testing period will be used as a research project to gather additional information regarding the special design needs of persons with disabilities.

ACKNOWLEDGMENTS

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BUT WILL THE ASSISTIVE TECHNOLOGY DEVICE BE *USED*?

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ABSTRACT

It is important to analyze the constellation of factors serving to influence the individual client's predisposition towards ATD use or non-use so that the most appropriate ATD for that person can be provided and the person's rehabilitation course and quality of life will be enhanced to the greatest extent possible. The Assistive Technology Device Predisposition Assessment (ATDPA) is introduced as a means of helping rehabilitation professionals obtain just such a comprehensive profile of their clients so that the most appropriate and effective rehabilitation interventions can be designed.

INTRODUCTION

A variety of factors influencing the decision to use or forego an assistive technology device (ATD) were identified through a comparative case study of adults with cerebral palsy or with spinal cord injuries. A complete description of the research design, the sample characteristics and the instrumentation are found in Scherer[1,2,3].

FINDINGS AND RESULTS

ATD use and non-use depend on many factors both within and outside of the individuals involved. Therefore, a variety of interactive and interdependent relationships need to be considered when planning to equip a person with an ATD.

The complex constellation of influences on ATD use does not preclude, however, a grouping and discussion of them. The following narrative focuses on four broad categories of factors (of necessity, oversimplifications) with there being great overlap among the factors both within and between categories.

1. Characteristics of the Disability

A. Disability type. It is important to consider an ATD in relation to each disabled experience. For example, those individuals who have had whole new worlds opened for them through technology (as is true for many individuals with CP) have different views of the role ATDs have played in their quality-of-life from those who have had to leave an able-bodied world behind because of a SCI. For some, ATDs do not just make up for limited function, but open up entire new vistas and make available new experiences. For others, ATDs are reminders of what they have lost. Many people with CP were unable to communicate with others before their communication ATDs. They did not experience losing something and regaining a portion of that through ATD use. An ATD that offers individuals the opportunity to speak for the first time in their lives is naturally perceived differently from purely augmentative devices. Someone able to go out to a restaurant for the first time because of the availability of a powered wheelchair, as may be the case for a person with CP, no doubt experiences this differently from a spinal cord injured person accustomed to walking in with friends.

Different physical disabilities are associated with different complications and sequelae, courses of treatment and rehabilitation. Participants with CP who use sophisticated ATDs believed they were usually viewed by others as having higher cognitive and linguistic abilities than CP users of simpler aids. However, people with SCI generally perceive a simple aid (such as splint giving a 3-point pinch) as a desirable status symbol because it often indicates higher functioning—and ingenuity.

Disability type, thus, is an important factor that can influence ATD use and the way that use is interpreted. Otherwise, it can occur that an individual is provided with an ATD that is impractical or inappropriate. For example, one woman with CP said that she has the motor control of a three-year-old and "you don't give a three-year-old a reacher."

B. Age at onset. The age at onset of a disability may affect ATD use. For instance, persons with a SCI who experienced injury at a relatively young age, a time when their personality characteristics were more malleable, tended to use ATDs and to have made positive changes in their lives. Those SCI participants injured later in life, and whose injuries were less severe, tended to be ATD non-users.

Varying lengths of time since the onset of the disability is a factor since the experience of coping with a disability may, over time, contribute to modifying adaptive behavior.

The age at onset of a disability as well as its severity can represent a major life change requiring modification in the most basic and taken-for-granted activities of daily living. Active young men who become paralyzed from spinal cord injuries and active middle-aged stroke survivors are examples of persons who experience major life changes.

C. Degree of severity of disability. The more limited an individual's functioning is, the more that person will need an ATD. For example, a C4 spinal cord injured person has little option but to use a powered wheelchair; a person with CP who has little or no intelligible speech will be a more frequent user of a computerized communication system than someone who has difficulty with only certain words. Not only do more severely disabled individuals require more equipment, but more *expensive* equipment.

2. Characteristics of the Person

A. Cognitive abilities and aptitude. People differ in both their desires and aptitudes to use ATDs effectively. Some people are just more "left-brained" than others. Also, many disabilities have concomitant head injuries associated with them that leave persons with cognitive deficits.

B. Personality traits. People with disabilities attach different meanings to what has happened to them and what their future is likely to be like. Preexisting temperament and ways of coping are just two factors that can influence the circumstances surrounding onset of injury or illness, the length and quality of the recovery and rehabilitation process, and the number of rehospitalizations. These factors in turn affect adjustment.

From the data provided by the users and non-users themselves, it appears that the users attribute their successful use of ATDs to inner motivation, desire (to talk, for example), and an unwillingness to be held back from self-expression and the pursuit of independence and their goals. ATD users tend to see their disabilities as an obstacle they need to, and can, surmount. They emphasize their new or regained capabilities and try to forget their disability, work around it, relegate it to lesser importance. Non-users, on the other hand, focus on barriers to their independence citing both obstacles posed by society and their own limitations. They exhibit socially withdrawn behaviors which they attribute to a non-accepting society.

While users portray their lives as fulfilling, non-users express less general life satisfaction. Users feel in control of quality-of-life and that it can be changed, improved. They actively strive towards societal integration in the workplace and in their interpersonal relationships. Non-users feel societal integration is either unattainable or undesirable and that they have little control over their quality of life and express a lack of motivation to overcome their disabilities. ATD users present themselves as meeting challenge head-on; ATD non-users present themselves as feeling defeated.

Many individuals with acquired disabilities, such as spinal cord injuries, can be reckless young individuals who are impulsive, easily frustrated and discouraged, and lack the necessary self-discipline and patience to become ATD users. For them, the assumption of the role of rehabilitation client entails a submission to rehabilitation professionals and the process of rehabilitation. It is an adjustment many clients not accustomed to dependency and subordination may be unwilling to make. Thus, the independent client who places a premium on individuality and personal freedom of choice will likely resist premature efforts to adopt ATDs—especially if the person is strong-willed and their basic ways of doing things are being pushed to change.

More emotionally mature persons, on the other hand, those who are well- and self-directed, patient and persistent, who are excited and encouraged by new things and love a challenge, those who focus on opportunities rather than loss and limitations, are the persons who more easily adapt to ATD use.

C. Judgment and Preference. Individuals with disabilities can misjudge what an ATD will and will not do for them. One person with CP, for example, may determine that an ATD will not improve her speech intelligibility significantly enough to warrant its use, while another equally affected individual may see an ATD as not only desirable, but indispensable.

Many persons express a desire to use an attendant or what they themselves have, however limited, as opposed to a mechanical replacement for their limited functions.

D. Outlook. Many persons with disabilities harbor hopes for a cure for their disability or say they are waiting for the mass availability of prematurely-touted experimental devices that they see as more desirable than currently available ones. Such hopes often serve to hinder their rehabilitation.

Other factors affecting one's outlook include depression and pessimism arising from the process of adjusting to their disability. For example, it frequently takes SCI persons seven or more years to come to terms with their disability and many refer to the drastic adjustments they must make by talking in terms of living two lives. One of the participants in this research said: "My first life was one of walking, this life is one of different ways of getting around and doing things."

3. Psychosocial Characteristics

A. Exposure and opportunity. Beyond individual physical and psychological characteristics, functioning depends on such factors as environment, resources (e.g. private insurance for specialized treatment) and opportunities (e.g. placement in a research center equipped with the latest rehabilitation technology), and the course of rehabilitation. Often, rehabilitation can seem like a "one-shot chance," as expressed by one SCI participant:

"I wish it was set up so that you could go home for a year and then come back. Just so you could get more work done in some areas, strengthen points you want to work on where you have a therapist who can give you ideas on how to make things better at home. I mean, don't go just cold turkey. Usually once you're done with rehab, that's it—you're done with rehab. But it would be great to have that individual help after a year or so."

Sex role can have an affect on ATD use. Women in many societies have traditionally received little exposure to technical perspectives and tend to be uninformed about and disinterested in the complex and sophisticated products of rehabilitation engineering efforts. Non-technically-oriented males, on the other hand, can feel even more threatened by ATDs since they may feel an additional assault to their egos because they lack skills that are traditionally male objects of interest.

Another important influence on ATD use is the type of socialization one received. Many individuals born with CP have led emotionally, socially, and cognitively impoverished lives and have fewer coping skills than SCI persons who received a "normal" socialization, with "normal" peers in a "normal" educational setting.

B. Expectations. The attitudes of others and their expectations of the client, as expressed through the intimate interactions of family life or through exposure to the values of society as a whole, can have a profound influence on people with disabilities and their expectations of themselves. The self concept, motivation and personal aspirations of an individual are shaped by social interactions and support that serve to control positive personal regard, resources and opportunities.

These influences on a person's achievement of rehabilitation goals are joined by the characteristics of the goal itself (explicit, proximate, not too difficult), and whether the experience of success or failure accompanied the process of goal achievement.

C. Social support. Social support systems have a profound influence on how people with disabilities interpret their experiences and evaluate their options and alternatives—and they affect what options and alternatives are presented in the first place.

An acquired disability often places sudden strains on family relationships and social resources. When the support network is altered, the person generally experiences further psychological distress. This psychological distress can trigger physical distress and medical complications, which in turn may lead to rehospitalization. The outcome of this chain of events can be further disorganization, disintegration and deterioration of the social support system.

While not all social ties are supportive, and when effective supportive aid is given it is important to know under what conditions the aid was actually given (i.e. what was said or done to attract that positive aid) it was found that ATD users tended to have more social support than non-users. For example, their families built ramps and modified the family home or their employer held a job for them. Family reluctance to have the person return home unaided, stable family relations, being the person responsible for family maintenance, were all positively associated with ATD use. The families of ATD non-users, however, tended to view the ATDs as requiring too much work and effort and said they didn't want them.

4. Characteristics of the ATD

A. Design factors. ATDs have a high rate of use when they are lightweight and portable, easy to use and set up, are cost effective to obtain and maintain, and are the same or similar to appliances used by the non-disabled population.

Disincentives to ATD use include their expense, lack of flexibility (e.g. they can only be used in a few settings), and user frustration with their speed or size or complexity. ATDs that "never seem to be there when needed," are seen as "not worth all the effort" and are clumsy to operate and are not portable, similarly are unlikely to be used.

Often ATDs are designed to look functional and utilitarian for funding sources and, as a result, leave many users feeling deviant and stigmatized. An ATD that looks "unusual" and does not meet the users real needs and desires is one that will end up stored in the closet, as will ATDs that are difficult to operate, cause discomfort, inconvenience the user, and require a lot of effort to use.

Non-use is also associated with family reluctance to have it used and the existence of easier alternatives (for example, families will do a lot to try and understand their child's speech before willing to adopt a communication ATD). Too, many people with disabilities have an aversion to replacing a natural function, however limited, with a technical device.

B. Service delivery. ATDs are not used if other support services are not there. A specially-equipped van, for example, is less useful when there are no handicapped parking spaces. People in rural areas may be unfamiliar with many ATDs because they haven't been exposed to them and may not have access to trained professionals to help them learn to use them properly.

People develop and change and unless they have ongoing access to rehabilitation professionals, they may stop using an ATD when all it may require to become useful again is some small adjustment or modification. People outgrow ATDs (either physically or developmentally) and need to be able to go to rehabilitation centers for upgrades and more developmentally appropriate ATDs.

Finally, the secondary gains associated with a disability and the economic disincentives to rehabilitation continue to exert an influence on ATD use.

IMPLICATIONS FOR PRACTICE

It is important for rehabilitation professionals to be able to assess their clients' characteristics and strengths and weaknesses for each factor influencing ATD use or non-use. To assist professionals in conducting just such a diagnostic analysis, an assessment system has been developed to guide insights into potential problem areas and to identify areas for intervention. This system, called the Assistive Technology Device Predisposition Assessment (ATDPA), is a reliable and valid one (having emerged from the actual experiences of consumers) and can be a valuable tool in the earliest stages of equipping persons with ATDs or in identifying needs for ATD modifications. Further information on the ATDPA is available from the author.

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P2.9

CONSUMER EVALUATION OF ASSISTIVE DEVICES

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This project compares user evaluation of employment-related assistive devices with user evaluation of independent living devices. Two small samples of adults with serious disabilities ($N = 24$) were matched and surveyed. Results show differences but not significance. Respondents also showed selective acceptance of devices as compared to using attendant care.

INTRODUCTION

This project examines consumer evaluation of assistive devices to study how acceptance of devices is associated with the type of social environment where devices are used. It is assumed that the social environments where devices are used may generate attitudes toward devices and patterns of device use. Specifically, in this study consumer evaluations were compared between device use in employment versus independent living environments. Subjects were asked to identify devices important to them, to evaluate those devices, and to compare their views about devices to the use of personal care attendants.

METHODS

Matched samples of disabled adults living at The Timbers independent living program in Wichita, Kansas, were given oral questionnaires. The survey defined assistive devices as "mechanical objects specifically intended to aid disabled persons to do what they need and want to do." Both samples consisted of employed residents who use devices either primarily at work or chiefly for independent living. The first sample of twelve subjects who used devices mainly for work were first identified by a managing engineer of Center Industries, a Wichita industry using adaptive devices. The independent living (IL) sample was then matched to that sample by age, gender, and educational level in order to control for possible influence by those variables. This sample also numbered twelve persons. The total research population numbered 24 Timbers residents.

The two samples were found to be very similar in disability. Both groups had primarily congenital, stable, serious disabilities such as cerebral palsy. More of the employment sample did use attendant care (83.3%) than the IL sample (75.0%). The employment device sample tended to work forty hours per week, while the IL device users tended to be employed part-time.

RESULTS

The employment sample was more likely to use one or two devices (41.7%), while the IL sample most often used one to three devices (58.3%) and also had a greater proportion using five or more devices (25.0% vs. 16.7%). Age showed moderate association with device evaluation. Younger subjects tended to be more positive (lamda = .20).

Although the employment group had been identified as users of custom adapted devices at work, they chose standard assistive devices such as electric or manual wheelchairs as their most important devices for work. The IL sample also chose electric or manual wheelchairs as their most important IL devices. Subjects in both samples reported that the freedom to move was what they liked best about their important devices.

Differences between the two samples on user overall evaluation of devices were observed. Those differences were not statistically significant as measured by the paired t-test ($t = .925$, D.F. = 11, p = N.S.). Some notable variations in device evaluation between samples were: the employment sample valued devices that were durable, looked good, made them proud, and worked well with other devices; the IL sample tended to value device convenience, comfort, and ease of use. The two groups differed in identifying device qualities to consider when obtaining a new device; the employment device group reported that sturdiness, efficiency, and durability were most important, while the IL subjects chose sturdiness, simplicity, and functionality as important new device characteristics.

Respondents in both samples saw devices as giving them more independence than attendants (Emp. = 33.3%, IL = 25.0%). Yet subjects rarely selected using devices over attendant care or "neither" on the choice of obtaining assistance in daily living. Both samples only preferred using assistive devices for mobility--not devices for personal hygiene, eating, or communicating. When asked what they liked best about attendants, the employment device group chiefly reported "there when needed," and the IL group primarily reported attendants "save time." What subjects tended to like least about attendants were waiting for them (Employment sample) and lost privacy (IL sample).

DISCUSSION

This small but tightly controlled research design did reveal distinctions between employment device users' attitudes and IL device users' attitudes. Although the attitudes reported by employment device users and IL device users do not vary by great degrees, the consistent trend shows variation. Employment device users show more concern with device capability (e.g., efficiency, durability). Independent Living device users tended to show more concern for the user-device interface (e.g., simple design, ease of use).

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P2.10

INDIVIDUALIZED TECHNOLOGY

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The proposal is set forth and supported that an individual technology approach to serving the needs of persons with handicaps is best. Mass production of adaptive equipment has not worked. Regardless of the number of "adjustments" built in, the array of disability is too wide and the combinations of disability, circumstance, and degree of handicap staggering. Professionals in engineering must be trained as members of interdisciplinary teams to provide devices, monitor their use, and make adjustments as needed.

INTRODUCTION

It is easy to see how the current situation arose in providing adaptive devices to persons with handicaps. Helping professionals are traditionally eager to serve as many persons as possible. Once a device was found which (for example) assisted one person with spastic quadriplegia to be lifted into a bathtub, it was assumed that the best way to serve the most people was to mass produce the item. It so occurred that during this period of mass production (1975-1985), there was large federal and state funding to support these efforts which lead to an even more eager mass-purchasing of equipment. A massive amount of technological equipment became available, and professionals tried to fit the individual to it. Professionals are slow to admit error. Especially in human-service fields where funding is often low, they hate to admit that money has been spent unwisely. Finally, however, enough data and experience has been gained to state that a new approach must be found (1,2). Individual need must be the basis for development of technological devices (3), and this must be accomplished through pre-service training of engineers to be members of interdisciplinary teams to provide devices, monitor their use, and make adjustments as needed.

BACKGROUND

In the fall of 1987, faculty from Engineering, Special Education, and Research Services combined efforts to initiate a project wherein interdisciplinary teams of students were formed to tackle the individual technology needs of various children and adults with handicaps. Team membership by discipline varied dependent upon the type of device needed and the disability type and degree being considered. For example, occupational therapists were needed on some teams, speech therapists on others. Likewise, mechanical engineering students were on some teams and electrical engineering on others. Engineering students were enrolled in courses requiring design and/or building of a senior-project device. Special Education students were enrolled in a graduate class for related services personnel requiring skill in use and adaptation of adaptive equipment for multiply handicapped students. The project was successful, and National Science Foundation funding was obtained. Now in its second year, the project has many successes to report.

METHODS

Students from all disciplines meet early in the semester for a general overview of objectives. Special education students are given two weeks to select a student/client/family in need of adaptive equipment. Special education students receive six-nine hours of instruction in administering an assessment device and then are required to collect this data on the individual to be served. Meanwhile, engineering students are made aware of commercially-available equipment. The two groups meet back together again. Special education students orally present the case studies, and teams are formed based on abilities of persons present and interest. Case studies not selected for further investigation at this time are saved as a file of future possibilities. Teams then proceed with individual contact, team consultation, and study to design and build a device. Data is collected on time and dollars spent as well as on client satisfaction. Projects are carried semester-to-semester when necessary, and new projects begun each time.

RESULTS

To date, twelve items have been built and given at no cost to the individuals with handicaps for whom they were designed. Another fifty-five case studies with designs have been developed, but are waiting to be built. Data indicates high student satisfaction with participation in a meaningful project and high client satisfaction with devices built.

DISCUSSION

Although funding has allowed for mass-purchasing of adaptive equipment over the past five to ten years, much of that equipment is left unused (2). Either it was not appropriate to begin with, or the circumstances changed, or no one could be found to modify/update/repair it. It is suggested that this univeristy-based pre-service training program is a way to solve this problem. Individual need should guide technology.

CONCLUSIONS

A third project year is being planned. Several lessons have been learned and are being implemented:

1. Students must be trained in the interdisciplinary process. It does not come naturally to share discipline-based expertise or to learn from other professionals.
2. Students must learn new skills. Engineers must learn many human relations and family consultation techniques; educators must lose their fear of technology.
3. Inter-agency co-operation is essential, as individuals to be served will likely be clients of other agencies concurrently.
4. Client circumstance is a very important variable in the design and provision of equipment. For example, there must be competent caregivers in the environment to look after the day-to-day maintenance involved if the individual cannot do this for himself.
5. Of most importance, the individual person with a handicap must always be the first consideration. Not just physiological, but psychological and emotional factors play a large role in successfully providing a person with adaptive equipment (2).

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P2.11

PRELIMINARY RESULTS OF SALARY SURVEY FOR REHABILITATION TECHNOLOGY SPECIALISTS

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INTRODUCTION

With general trends in health care indicating current and future shortages of allied health professionals, recruitment and retention strategies have assumed significant importance in many areas of service delivery. These issues are reflected in organizations which provide or promote the use of rehabilitation technology. Forces generated by third party payer needs for quality assurance in funding rehabilitation equipment and implementation of federal legislation for provision of rehabilitation technology have stimulated discussion of the qualifications and role of the rehabilitation technologist, needs for certification and issues of supply and demand for such specialists. In an increasingly competitive recruitment environment for health professionals, rehab. technology service delivery facilities will certainly need to explore salary scales which are effective in attracting and retaining qualified staff. This paper describes the results of a salary survey of existing specialists who are members of RESNA. Although statistical significance is limited due to the size of the response, some trends are apparent.

METHODS

A questionnaire, circulated by publication in Rehabilitation Technology Review, Summer, 1988, (circulation approximately 1000) was designed to determine respondents:

- practice setting
- geographic location
- title, discipline, job description and responsibilities
- academic training and years of experience (total professional and specializing in rehabilitation technology)
- yearly salary

In providing salary information, some respondents only indicated a $5,000 range or the category "more than $50,000" while others indicated exact annual salary. To analyze trends, when a range was indicated, the midpoint was used as reported salary (ex: $35,000 - $40,000 was assumed to be $37,500) and $50,000 used for calculations in the absence of specific salary when "more than $50,000" was checked. Reported salary figures were then adjusted for geographical differences in cost of living according to the index "Comparative Living Costs in U.S. Metropolitan Areas" . Factors based on middle income budgets were used to normalize data to equivalent salaries in cities indexed as 100 (Chicago and Cincinnati). Since the index does not contain all cities represented in the survey response, the index for the city closest to the respondent's was used.

Correlations of salary with title, job descriptions and responsibilities expressed as a percentage of time could not be made due to a wide variability and respondent's indication of multiple job descriptions within a single position. A total of 58 questionnaires were returned and salary information was analyzed for three variables: discipline, type of facility and highest academic degree. For each variable, cumulative frequencies plotted against adjusted salary allowed calculation of salary at the 50th percentile. In addition, mean adjusted salary, mean total years of professional experience and mean years of experience in rehabilitation technology were calculated.

RESULTS

Approximately 80% of respondents clearly classified themselves into one of four categories of practice: engineering, physical therapy, occupational therapy, speech and language pathology and adaptive equipment technician services. These categories excluded assistant therapists and engineers with less than a bachelor's degree; these individuals, few in number, were classified in the "other" category. The "other" category also includes individuals with single representation in the survey, multiple areas of practice, primarily educators or roles uncommon in rehabilitation technology services.

Facility and organizational information was categorized according to 5 models with "other" described below. The "Hospital" category includes rehabilitation and general hospital, outpatient and clinic service delivery; clinical delivery systems taking the same forms and identified as "University Affiliated" constituted a separate category. Organizations specifically dedicated to vocational or educational goals or part of a general educational facility comprised the "Educational/Vocational" category. Service delivery in a school or residential setting designated specifically for groups with disabilities fell into the "School/Residential" classification. A few agencies consulting or coordinating technology for goals not specifically educational or vocational were categorized as "Disability Service" organizations. "Industry/Manufacturer" included DME vendors and private companies providing designing, architectural and/or engineering services.

DISCUSSION

The data on a small but equal number of O.T.s and P.T.s indicate similar salaries with O.Ts having slightly less total and specialized experience. When considering all respondents according to setting, university affiliated practitioners appear to earn somewhat less than those in free standing hospital clinical facilities. As one might expect, practice in commercial settings and individuals holding higher degrees with more extensive total experience are associated with higher mean adjusted salaries.

The data and correlations we've noted are certainly limited in significance and reliability due to sample size but are valuable first steps in documenting national salary and practice trends in rehabilitation technology. Continued work on this survey will 1) examine factors which might clarify the salary discrepancy seen in university affiliated centers 2) compare findings to available salary survey data for general or specialized practitioners in professional associations 3) search for more accurate indexes for geographical adjustment of salary 4) refine the questionnaire and 5) expand the4 sample size.

REFERENCES

1. M.B.A. Employment Guide, 1986-87 Edition, Association of MBA Executives Inc., 305 Madison Avenue, New York, NY 10165

TABLE 1

Discipline	n*	%	Mean Adj. Salary	Salary at 50% Percentile	Mean Total Exper.	Mean R.T. Exper.
Engineers	25	43	$36,782	$31,000	11	6.6
Physical Therapists	7	12	34,432	33,500	13	6
Occupational Therapists	8	14	34,413	33,500	10	4
Speech & Language Pathologists	3	5	28,230	28,000	16	6
Adaptive Equipment Technicians	3	5	19,713	-	17	7
Other**	12	21	33,265	28,500	12.1	8

* n = number of respondents
** Examples of disciplines: Social Science (1), Special Education (2), O.T. Assistant (1), Engineer-P.T. (1), Engineer-Prosthetist/Orthotist (1), Certified Orthotist (1), Computer Science/Economics/Business (1), etc.

TABLE 2

Setting	n	%	Mean Adjusted Salary	Salary at 50% Percentile	Mean Total Exper.	Mean R.T. Exper.
Hospital	20	34	$31,660	$31,500	11.8	3.5
University Affiliated Hospital	10	17	29,493	28,500	9.5	6.0
Educational/Vocational Agency	5	9	29,920	28,500	12.2	3.3
School/Residential Setting	10	17	29,060	27,500	9.5	7.5
Disability Service Agency	3	5	34,265	-	6.5	4.5
Industry/Manufacturer	6	10	46,508	35,000	13	11
Other:						
Academic (Professor)	1		55,000	-	3	3
"	1		53,500	-	30	30
Research Institute	1		72,540	-	16	9
"Consultant" Co.	1		38,625	-	29	15

In analysing responses for highest academic degree, individuals indicating credits toward a higher degree or "near completion" were categorized for the degree actually held rather than the one anticipated.

TABLE 3

Degree	n	%	Mean Adjusted Salary	Salary at 50% Percentile	Mean Total Exper.	Mean R.T. Exper.
Doctorate	5	9	$43,368	$37,000	13	5
Masters	27	46	38,963	31,500	14	5.1
Bachelors	18	31	32,421	29,500	12	7.5
Associates	4	7	26,994	28,000	12.6	6.2
Other*	4	7	27,363	22,500	14	10

* Other included individuals with no academic degree, some college credits or non-degree training courses.

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P2.12

TechWorks - Rehabilitation Engineering Startup Program in New Mexico

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Abstract

The DVR of New Mexico has began statewide rehabilitation services through a contract awarded to Adelante Development Center's TechWorks program. The contract specifies mobile workshop and evaluation services, information referral, and establishing working procedures with the DVR system. Special emphasis is to be placed on training of field counselors and using a "broker" model for service delivery where possible.

Introduction

Adelante Development Center, Inc., an agency serving the severely disabled in Albuquerque, New Mexico, set out in the Spring of 1988 to establish a program that would bring the benefits of technology to the disabled. It seemed especially ironic that in a state that was famous for its national laboratories and being the birthplace of many scientific and technological discoveries - no one was systematically providing a service to apply technology to the state's adult disabled population.

Adelante began by identifying certain clients within it's day training program and implementing simple communication boards and adapted toy devices. With interest building, space within the building was "appropriated" for an adaptive equipment laboratory, and proposals were sent out to several funding sources. Quickly the program received over $15,000 to purchase computer and communications equipment.

In the Fall of 1988, the New Mexico Division of Vocational Rehabilitation requested proposals to establish Rehabilitation Engineering Services for the state DVR system. Adelante was primed for a quick response, and was subsequently awarded the contract.

Scope

The scope of the program encompasses two full time staff positions, a shop/lab in Albuquerque, a van-based mobile workshop, the development of procedures with DVR, and extensive training and information services to the DVR system. DVR recognized the need for training of its field staff in particular. TechWorks is contracted to provide a series of three workshops around the state to counselors.

TechWorks plans on cultivating the extensive engineering expertise that exists in New Mexico through the establishment of an advisory council, consisting of representatives from the national laboratories, universities, and high-technology companies that are located in the area.

Facilities

TechWorks currently occupies 1500 square ft of warehouse space in the same block as its parent facility Adelante industries. This allows TechWorks to access important resources housed in the main Adelante Industries building, Yet at the same time enjoy a great degree of autonomy in their own building. The layout of the building includes three finished offices that are used to house a library, computer assessment equipment, and office for the two full time staff. The remaining space is divided into two shop areas. One for wood and metal working, the second is a garage type space used as a "home port " for the mobile workshop van.

Brokers

In addition to the start-up nature of this project and the need to serve a large, rural area, we think that several aspects of our project would be of interest to other RESNA members. Those aspects include the decision by DVR to contract out such services and the close support and involvement that DVR is providing in seeing that an efficient and cost-effective system of rehabilitation engineering for New Mexico is developed. The model being followed is one where we see ourselves as a "broker" - providing engineering assessments and recommendations, and using third-party equipment suppliers as much as possible, and providing extensive follow-up and "quality-assurance" thereafter.

The metaphor of a "broker" also extends to the collection and dissemination of information. We are establishing a state-wide information service and a resource library. This information will be accessible to consumers, counselors and other interested parties through us, and eventually will be directly accessible to the public.

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IDENTIFYING THE TECHNOLOGY TRAINING NEEDS OF OCCUPATIONAL THERAPISTS

N. Somerville, D. Wilson and K. Shanfield

INTRODUCTION

The tremendous growth of technology has made it difficult for rehabilitation professionals to keep abreast of new products and effective methods for their selection and use (Trefler, 1987). In order to take advantage of the potential of technology to assist persons with disabilities, more professionals with skills in assessing technological needs, awareness of options and knowledge of appropriate methods for delivery of services are needed (Vanderheiden, 1987). Providing the specialized education or training to these professionals, however, is an immense problem because of the variety of disciplines involved and their different training needs. In an effort to address this problem and yet have an attainable goal, this project initially focuses on identifying and meeting the training needs of one discipline -- that of occupational therapy. Results of this initial phase of the project will later be applied to development of training programs for additional disciplines.

METHODS

In this first year of the project, activities have been focused on identifying the technology training needs of occupational therapists and determining how these needs can best be met. To meet these objectives, a Task Force of technology experts and/or educators has been organized and a survey of occupational therapists has been conducted.

The Task Force, a multidisciplinary group, consists of individuals selected because of interest, experience and/or current involvement in technology training for rehabilitation professionals. The first activity of the Task Force has been individual review and critique of written ideas for content of a survey of occupational therapists. The Task Force will also convene to review results of the survey and to discuss options for development and dissemination of training.

A survey was designed to determine the training needs of occupational therapists, as identified by therapists themselves. Two survey instruments were designed, one for occupational therapists in general, and one for occupational therapists who have more experience or interest in rehabilitation technology. The general occupational therapists were asked to respond to survey items based on what they believe they personally need. The more experienced, "expert" occupational therapists were asked to respond to items based on their perceptions of the training needs of other, less experienced therapists. These occupational therapists were also given the opportunity to identify any of their own training needs.

The sample which was surveyed by mail consisted of 2700 occupational therapists nationwide. Of this sample, 2500 were randomly selected from the special interest sections of physical disabilities, gerontology and developmental disabilities. These individuals comprised the general occupational therapist group. The remaining 200, (the experts) were selected from the RESNA membership mailing list, technology related literature, and from names supplied by the American Occupational Therapy Association (AOTA).

The survey instrument is divided into four categories: demographic, experience with technology, continuing education experience, and training needs. The first category has standard demographic questions, but also includes items, such as the type of work setting and whether or not the respondent works in a rural area. Responses to these items may affect the type of training developed and the method of dissemination used in the project. The section on experience is geared toward determining the level of the respondent's experience with types of technology and various technology resources. The continuing education experience category includes items related to types of programs the respondent has attended, and what educational media and forums are preferred. The last section, training needs, provides an opportunity for the occupational therapist to identify his or her needs for training and/or education. This section presents an extensive list of questions that represent knowledge and skills necessary for effective application of technology. The respondent is asked to indicate to which questions he or she needs answers. Another item in this section was designed to identify specific types of technology which respondents need to know more about.

The two surveys, which require mostly check responses, were mailed with a cover letter and glossary to the sample of 2700 occupational therapists. We anticipate a response of well over 1000, which will allow for extensive data analyses. The analyses will be completed and results of the survey presented at the RESNA Conference in June, 1989.

REFERENCES

Trefler E: Technology applications in occupational therapy. American Journal of Occupational Therapy, 41(11):697-700, 1987.

Vanderheiden G: Service delivery mechanisms in rehabilitation technology. American Journal of Occupational Therapy, 41(11):703-710, 1987.

ACKNOWLEDGEMENT

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P2.14

A LATCH CIRCUIT FOR REHABILITATION TECHNOLOGY

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ABSTRACT

A useful circuit for an on/off latch is described. Circuit notation is suitable for rehab. technologists not well versed in electronics.

INTRODUCTION

Rehabilitation technologists involved with special switch accessories may find it economical and useful to construct their own. The use of experimenters' printed circuit boards simplifies construction.

METHODS

I include a schematic for the circuit and a component layout for use with readily available prepared circuit boards. Fig. 1 is an example of such a board.

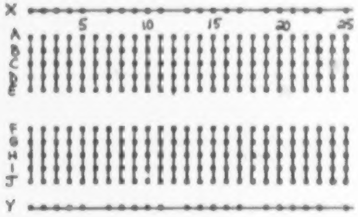

Fig. 1 Printed Circuit Board

Coordinates on the schematic corresponds to those printed on the prepared board. Push the components through the non-metallic side of the perforated board following the number letter grid. Solder the leads to the metal contacts on the reverse side. The X line is continuous all the way accross, and you connect it to the positive side of the battery, or "high", through an on/off switch. Connect the negative side of the battery, or "low", to the Y line. Perpendicular to the X and Y lines run the numbered lines. They, too, are continuous except for a break in the middle. If you can't fit a component's lead in the hole I specify in my drawing, you may put it through any free hole on the lead's corresponding metallic line. If you cut the printed circuit board in half you can make one circuit with each half.

Tips

1) Components.

Capacitor: If a capacitor has a plus sign you must face it in the direction specified in the circuit diagram.

Transistor: B=Base, C=Collector, and E=Emitter.

Diode: The end of the component with the line on it corresponds to the end of the circuit symbol with the line on it.

Semiconductor: Chips are numbered counterclockwise. A half moon or dot is stamped into the end with pin 1.

2) Soldering. The soldering iron must be tinned with solder. Heat the work, not the solder. Apply tip to the work then apply solder to the work at the point of tip contact. After removing the tip allow the solder to cool undisturbed for three or four seconds until it turns cloudy. Use just enough solder to fill the hole that the lead is in. Use rosin core solder. Put many components in at once. Tape them on top. Flip the board and solder them. Clip the leads and move to the next bunch.

3) Chip insertion. Never solder a chip into your circuit. Solder a socket the same size as the chip into the board and plug the chip into it after soldering everything else.

4) Reading a schematic. A circuit is laid out from left to right. Input is on the left. Output is on the right. The plus side of the battery is at the top of the diagram, and the negative side is at the bottom.

5) Metric Values. $K = x10^{3}$ $M = x10^{6}$
$m = x10^{-3}$ $u = x10^{-6}$

6) Tools and Materials. For convenience I include Radio Shack part numbers but any electronic retailer has equivalent parts.

Soldering Iron, etc.	64-2802
Pliers	64-1843
Cutters	64-1841
Stripper	64-2129
Voltmeter	22-212
Printed Circuit Board	270-170
22 Ga. Wire	278-1295
18 Ga. Zip Cord	278-864

Use the 22 Ga. wire for your circuit connections, stripping the part that inserts into the board. Use the zip cord as your plug wire.

Latch Circuit

This circuit transforms any momentary switch into a latching on/off switch.

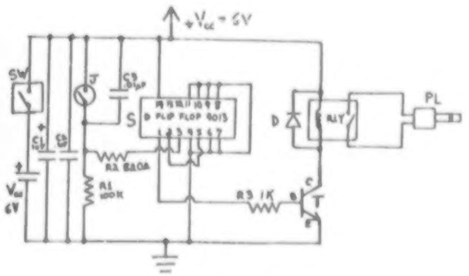

Fig. 2 Latch Schematic

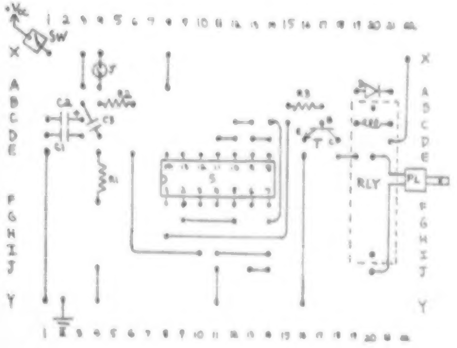

Fig. 3 Latch Circuit Board Layout

Parts:

Battery Holder, 4AA cells	270-391
C1 Capacitor, tantalum 1uF	272-1434
C2 ", ceramic .1uF	272-109
C3 "," .01uF	272-1065
D Diode, 1N914	276-1620
J Jack, 1/8"	274-251
PL Plug, 1/8"	274-286
Project Case	270-221
RLY Relay, 5V Reed	275-232
R1 Resistor, ¼W 100K	271-1347
R2 "," 820Ω 470Ω	271-1317
(Twist together)+330Ω	271-1315
R3 "," 1K	271-1321
S Semiconductor, Dual CMOS D Flip-Flop	276-2413
Socket, 14 pin	276-1999
SW Switch, on/off	275-602
T Transistor, NPN2222	276-1617
Vcc=6V, 4 AA cells	

Note that the 4013 D flip-flop is very static sensitive so store it in foil. Touch the foil before picking it up. Put it into its socket as a last step. Be sure the battery is turned off when you install or remove this chip.

Explanation of Circuit. When input pin 3 of the 4013 D flip-flop is brought to battery high by closing the input switch, its output pin 1 flips from battery low to battery high. The transistor turns on and the relay coil is energized. The relay contacts close, shorting the plug. If you bring the input pin 3 high again, output pin 1 goes low, which turns off the transistor and de-energizes the relay coil. The output contacts open.

Troubleshooting. If things are amiss first check that plus battery is reaching the places it should according to the circuit diagram. Use a voltmeter. Then if pin 3 doesn't go from battery low to battery high when you close your switch check the connections to the left of the chip. If pin 3 goes from low to high but the output pin 1 does not change values, check the connections into the chip. If output pin 1 changed values but the plug does not change condition, check the connections to the right of the chip. As a last resort replace the chip, after turning the battery off. -

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PROVIDING COMPUTER ACCESS IN A PATIENT LIBRARY ENVIRONMENT

P2.15

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ABSTRACT

This presentation will describe the development of a hospital-library program to provide patients, including those with physical disabilities, with independent access to a range of personal computer hardware, software, and related adaptive equipment. The "Personal Computing Station" has vocational, personal, and educational uses, and provides access to information databases for disabled persons.

INTRODUCTION

New York State Governor Mario Cuomo's Task Force on Technology and Disabilities, appointed in 1987, examined issues regarding disabilities and suggested specific directions for advancing the availability of special technology. This presentation describes a project which focuses on the task force's recommendations to create "product demonstration centers on a pilot basis" and "to provide an environment for consumers...to gain greater familiarity with available technology."

At Helen Hayes Hospital, the Patient Library and the Center for Rehabilitation Technology worked together to develop a "Personal Computing Station" (PCS) to provide all patients, including those who cannot use a computer keyboard, to try, learn, and perform personal computer applications relevant to home, school, and business situations. This mobile, adjustable work station, adapted for use by persons with disabilities, emphasizes independent living, vocational adaptation, education, and leisure activities. It enriches the therapeutic process of rehabilitation with the advances in technology by providing all patients independent access to a range of personal computer hardware, software, and peripherals, including those available to everyone, and those specially adapted for persons with disabilities.

NEEDS

Persons with disabilities need access to microcomputers for all the same reasons as able-bodied persons. In order to gain such access, they may require adapted hardware and software which is not generally available in schools, offices, and home computer stores.

The PCS at Helen Hayes Hospital also serves to augment the computer access program that is part of the Center for Rehabilitation Technology. This program evaluates patients with regard to computer use and helps them choose adapted hardware and/or software to provide effective access to microcomputers. During the evaluation process, patients need time to practice at length with the chosen access methods they are considering, so that before a final decision is made, the patient feels confident that the selected adaptation(s) is the correct choice.

PROCESS

The PCS was established with grant funding from the Library Services and Construction Act, which grants money to libraries to improve their services to their users. Once the lengthy application process was completed and the money was granted, the project was implemented in several stages:

(a) Ordering the furniture, computer hardware and computer software

(b) Writing procedures for managing and scheduling the PCS

(c) Assembly of the PCS components, and labelling of each individual piece

(d) Development of a list of components with directions for their use. This enables persons not familiar with computers and special access to assist disabled patients with setting up the PCS for their needs

(e) Some training of library staff and volunteers, to familiarize them with the components

(f) Development of a format for recording the personalized computer access strategy for each individual who needs special access. This strategy needs to be written in a very simple, step-by-step manner that is comprehensible to persons with little or no computer expertise

(g) A variety of efforts to publicize the existence of the service throughout the Hospital community

(h) Ongoing evaluation of the PCS to determine amount of use, satisfaction with the PCS itself and workability of the policies and procedures through which it is run.

EQUIPMENT

A number of components make up the PCS. First, the standard microcomputer hardware and mainstream application software were selected. This is supplemented by a variety of equipment which either adapts the standard keyboard, or replaces it with an alternate input device. Also included is special software required for the alternate input methods, or which increases input speed in a variety of ways. The last component is the workstation furniture, which is mobile, and highly adjustable, to enable the PCS to be used in different settings and to permit optimum positioning of the components for individuals of different sizes, different needs, and using different seating arrangements.

CONCLUSION

The Personal Computing Station developed at Helen Hayes Hospital meets the need for adapted computer access in a rehabilitation hospital setting, and would also be appropriate in hospitals, nursing homes and other health care facilities, educational settings, independent living centers, and public libraries.

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TIMER AND SOUND-ACTIVATED SWITCH CIRCUITS

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ABSTRACT

Useful circuits for a timer and a sound-activated switch are described.

See the paper entitled A Latch Circuit for Rehabilitation Technology in this volume for specific fabrication details.

Timer Circuit

Activation of an input switch causes the output to close for a variable period of up to 24 secs. Repeated switch activation during the timed period has no effect. Only when the preset time is exceeded is the timer receptive for retriggering.

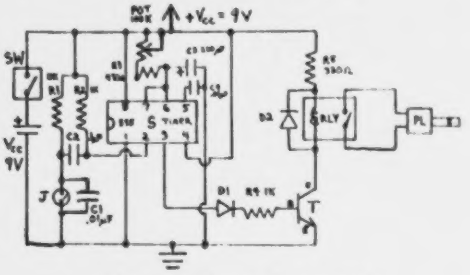

Fig. 4 Timer Schematic

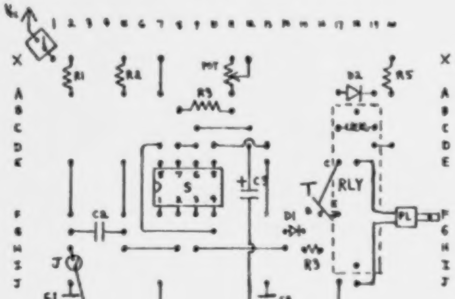

Fig. 5 Timer Circuit Board Layout

Parts: Battery Holder, 9V	270-326
Battery Snap, 9V	270-325
C1 Capacitor, ceram. .01uF	272-1065
C2 ", " .1uF	272-109
C3 ", electrolytic 220uF	272-1017
C4 ", ceramic .01uF	272-1065
D1 Diode, 1N914	276-1620
D2 ", "	"
J Jack, 1/8"	274-286
POT Potentiometer, 100K	271-092
Project Case	270-221
R1 Resistor, ¼W 10K	271-1335
R2 ", " 1K	271-1321
R3 ", " 470Ω	271-1317
R4 ", " 1K	271-1321
R5 ", " 470Ω	271-1317
RLY Relay, 5V Reed	275-232
S Semicond., 555 Timer	276-1723
Socket, 8-pin	276-1995
SW Switch, on/off	275-602
T Transistor, NPN2222	276-1617
Vcc= 9V battery	

Explanation on Circuit. When trigger pin 2 is brought from battery high to battery low by closing the switch in the jack, the output pin 3 goes high for time $t(secs)=1.1(R3+RPOT)(C3)$. If RPOT is turned to max, $t=1.1(470+100\times10^{3}\Omega)(220\times10^{-6}F) = 24$ secs. If RPOT is turned to zero, $t=1.1(470\Omega)(220\times10^{-6}F)=.11$ sec. When output pin 3 is high it turns on the transistor, energizing the relay and closing the plug.

Troubleshooting. If your timer does not work check that plus battery is reaching the places it should, using a voltmeter. If output pin 3 does not go from low to high when you close the switch check all the connections to the left of and into the chip. If pin 3 goes from low to high but the plug does't short, check the connections to the right of the chip. Replace chip if need.

Sound Activated Circuit

This switch is variably sensitive to sound and has a predetermined output duration. The input microphone may be remotely mounted. Attach the **microphone to the** circuit with a generous length of microphone wire. A sound will activate the switch for half a second. $t(secs)=1.1(R4)(C4)$. You can vary this to suit the client. Microphone sensitivity can be easily varied by adjusting the pot. Each time the switch is used the sensitivity must be set to exclude room noise.

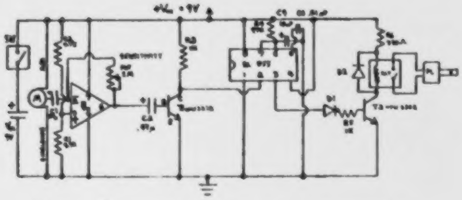

Fig. 6 Sound Switch Schematic

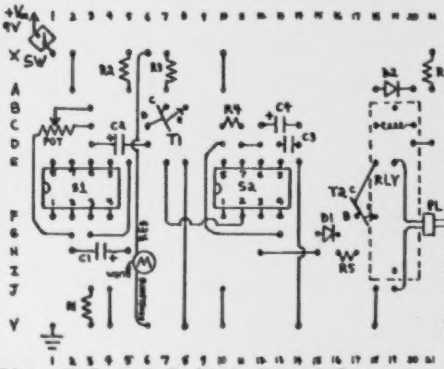

Fig. 7 Sound Switch Board Layout

Parts:

Battery Holder, 9V	270-326
Battery Snap, 9V	270-325
C1 Capacitor, tantalum .47uF	272-1433
C2 ", " "	"
C3 ", ceramic .01uF	272-1065
C4 ", electrolytic 10uF	272-1025
D1 Diode, 1N914	276-1620
D2 ", "	"
M Microphone	270-092
Microphone Wire	278-1276
PL Plug, 1/8"	274-286
POT Potentiometer, 1M	271-211
Project Case	270-221
RLY Relay, 5V Reed	275-232
R1 Resistor, ¼W 4.7K	271-1330
R2 ", " "	"
R3 ", " 1K	271-1321
R4 ", " 47K	271-1342
R5 ", " 1K	271-1321
R6 ", " 330Ω	271-1315
S1 Semiconductor, 741 Op-Amp	276-007
S2 ", 555 Timer	276-1723
Sockets, 8 pin	276-1995
SW Switch, on/off	275-602
T1 Transistor, NPN2222	276-1617
T2 ", "	"
Vcc=9V battery	

Explanation of Circuit. When the sound picked up by the microphone is greater than the threshold set by the 741 op amp the transistor turns on. This brings input pin 2 of the timer to battery low. Output pin 3 goes high for t=1.1(R4)(C4), or half a second. This turns on the relay, shorting the plug for half a second.

Troubleshooting. If the circuit does not work use a voltmeter to check that all the points of the circuit that should be at plus battery are. If the 741's pin 6 doesn't go from battery low to battery high regardless of where you set the pot or how loudly you speak into the microphone, check the connections left of T1. If pin 6 goes from low to high but the 555's input pin 2 does not go from high to low, check the connections into T1. If the 555's input pin 2 goes from high to low but its output pin does not go from low to high, check the connections into the 555 chip. If output pin 3 does go high but the relay doesn't short the plug, check the connections to the right of the 555 chip. As a last resort replace the chip.

Finish all circuits by using hot melt or screws to mount them in the project case. Bring the plug and microphone wires out through holes, knotting them for strain relief. Mount the jack, potentiometer shaft, and batteries on top.

ACKNOWLEDGEMENTS

I thank United Cerebral Palsy Associations of New Jersey for their support.

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EFFECTIVENESS OF MODIFICATIONS MADE TO A STANDARD U.S. POSTAL SERVICE MAILBAG

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ABSTRACT

Chronic problems and complaints of the neck, shoulder and back are experienced by letter carriers. This problem seems to be due, at least in some degree, to the "one strap" method of carrying the mail satchel. A modification involving the use of a second strap was made to a standard US Postal Service mailbag. The present study demonstrates the reduction of pressure under the straps.

INTRODUCTION

A pilot study was conducted to test the effectiveness of a modification made to a standard US Postal Service mailbag. The modification involves the addition of a second shoulder strap for added support. A number of problems have been identified in relation to the present bag. These include:

Back pain;
Neck and shoulder pain, possibly due to nerve impingement;
Awkward maneuvers are created;
Balance on slipping surface.
Loading bag from car is sometimes difficult

The present study was designed to investigate several biomechanical variables that might contribute to the problems described above.

Hypotheses. A number of hypotheses were developed to explain differences between the original configuration of the mailbag and the addition of the new strap. These include:

1. Pressure under the strap would be reduced with the addition of the new strap. Pressure of the strap will contribute to neck and shoulder pain. The higher the pressure the more likely there will be nerve impingement.
2. There would be a difference in back muscle activity. Assuming the load of the bag is redistributed there should be a difference in muscle activity.
3. There would be a redistribution of load under the feet.

METHODOLOGY

A number of measurement techniques were developed to test the above hypotheses in a pilot study. There was no attempt to be comprehensive or to collect data for statistical analysis.

Subjects. Five adult men participated in the study. None had a history of low back pain or had any other medical complaints. None of the subjects were professional mailmen. A mailbag containing 35 pounds of books was used throughout the testing.

Pressure Measurements. Pressure measurements were taken using an Oxford Pressure Monitor. This device uses small plastic air cells that were fitted between the straps and the subjects' shoulders. Four air cells were placed under each of the straps, the original and the new strap. Sequential pressure readings were taken from each of the four cells. The readings from the four cells were then averaged to give a single index of pressure.

Back Muscle Activity. Electromyographic (EMG) signals were obtained from both the right and left erector spinae muscles of the back. These are the muscles that help in extending the trunk and that provide balance when one stands upright. Surface electrodes were placed on the subject's back in the lumbar region of the back. The signals from the electrodes were passed through an RMS to DC converter. This converter provided a single number representing the muscle activity.

Weight Distribution. Subjects were asked to stand with one foot on a scale while the other foot was supported by a platform level with the platform of the scale. In this way, weight distribution between the two feet could be observed by reading the scale.

Protocol. Each subject was fitted with EMG electrodes and was asked to pick up the bag using only the original strap. The subject then stood with weight distributed between the scale and the platform. Pressure, EMG and weight measurements were then taken. After the measurements were taken the subject was given 5 minutes rest. Measurements were then repeated using the new strap. A second trial was performed with all measurements being taken a second time.

RESULTS

The pressure measurement showed the biggest difference between the two configurations of the bag. It appeared that the pressure under the original strap was significantly reduced by the addition of the new strap. When two straps were used, the pressure was fairly evenly distributed between them. However the pressure under the original was somewhat higher than that under the new strap (Fig. 1). There did not seem to be any significant difference between the two conditions in back muscle EMG signals or in weight distribution.

DISCUSSION

Reduction of shoulder strap pressure might help to reduce the risk of nerve impingement that might cause neck and/or shoulder pain. While the pressures measured were still very high, there did seem to be a dramatic reduction with the addition of a second strap.

EMG signals were recorded only from the erector spinae muscles, which are of particular importance in the study of low back pain, and there was no difference between EMG signals recorded under the two conditions (one strap vs. two). However, measurements of the shoulder musculature, such as the trapezius muscle, might have revealed such a difference. There was also no apparent difference in load distribution between the two conditions; however it was observed that the subjects modified their postures to accommodate the bag in its different configurations, and subjects noted that this was very easy to do. Thus, the method used might not have been a reliable way of measuring load distribution.

CONCLUSIONS

This pilot study demonstrated significant differences in how a mailbag is supported when a new strap is added. The second strap significantly reduced the amount of pressure under the original strap, thus possibly minimizing the risk of pressure-related pathologies such as nerve impingement. It is suggested that further studies be conducted to investigate differences in shoulder musculature. More subjects should be tested, including professional mailmen, both those familiar with the new strap and those using the original configuration of the bag.

Subjective evaluations of the bag should also be obtained from professional mailmen who have used the modified bag over a period of time.

ACKNOWLEDGEMENTS

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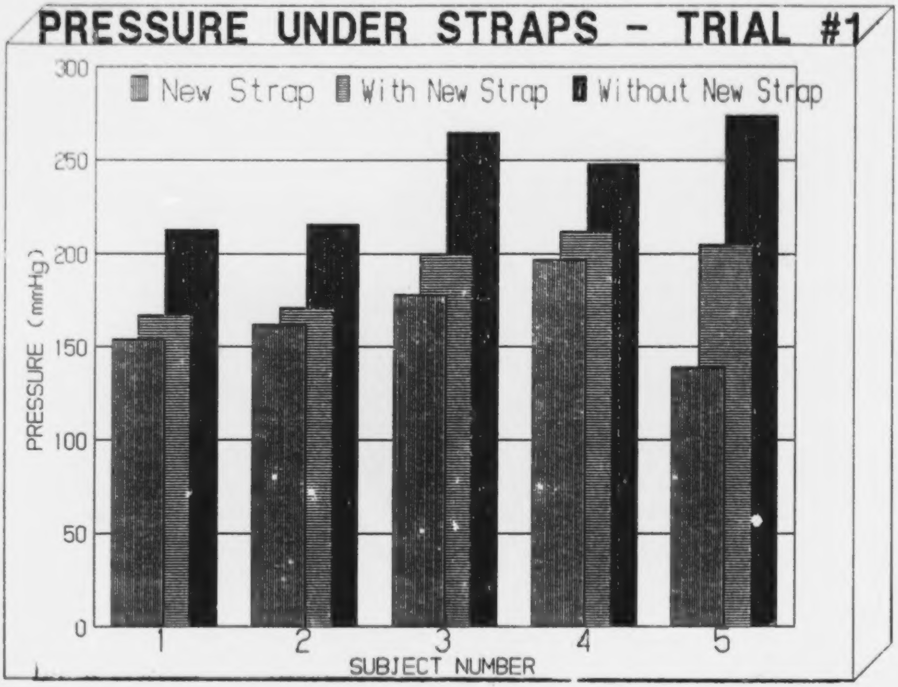

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ENGINEERING STUDENT DESIGN PROJECTS IN PHYSICAL, OCCUPATIONAL AND SPEECH THERAPY

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One cost effective method of delivering custom rehabilitation design services is through the use of carefully selected and supervised engineering student design projects. A number of such projects in the area of physical, occupational, and speech therapy equipment have been completed for a community infant habilitation services program. These include lower and upper extremity exercise systems, visual and audible stimulation devices, and alternative communication systems. In each case the clinical objective is addressed with attention to the overall needs of the user for equipment which is interesting in appearance and function. These projects provide a needed resource to the rehabilitation facility and an outstanding educational experience for the designers.

INTRODUCTION

One component of our ongoing program in rehabilitation engineering service delivery utilizes senior bioengineering students as part of project teams. These teams identify, design and implement devices and systems for use by either individual clients, or for use by therapists and teachers in working with groups of clients. This work takes place in conjunction with several settings including units of the Texas Department of Mental Health and Mental Retardation, local school districts, and the Children's Center for Developmental Therapy in Houston. The latter is a private, non-profit organization with a program in infant habilitative services including physical, occupational and speech therapy. In working with this facility the participating students have developed a number of devices for use by the therapy staff.

PROGRAM ORGANIZATION

Design projects are initially identified through a group meeting between the therapists, engineering students, and engineering faculty. During the meeting ideas are refined and measured against the criteria of cost, time and complexity that is consistent with resources and the academic time frame. Following initial selection, the defined needs are further analyzed and designs are developed under faculty supervision for review with the Center's staff. Final designs are constructed by the students, and delivered to the Center along with appropriate documentation. Follow-up design review is then obtained and designs are modified as necessary. Since the completed projects cover a wide range of complexity, some students may work on several projects while others may concentrate on only one more difficult project. At the present time there is no cost to the Center for this program as a result of funding to the Bioengineering Program from the National Science Foundation which covers direct project expenses. Faculty time is contributed.

PROJECTS COMPLETED

Vertical Pole Walkway. This project is a substitute for traditional parallel bars for providing support during training and exercise in walking. The objective was to provide discontinuous support so that weight shifting and related walking skills could be developed. To achieve this goal a walkway was designed which has two rows of vertical poles in place of the normal parallel bars. Selected poles can be removed to increase the spacing. There is a light at the top of each pole such that a moving goal can be controlled by the therapist. The lights also provide a stimulus to the child to keep their head upright while walking instead of watching their feet.

Stationary Exercise Tricycle. In this design, a standard child's tricycle was mounted on a platform with an adjustable mechanical resistance for the front wheel. A display was also provided in which lights on the wheels of a motorcycle figure rotate as the tricycle is pedalled. The use of a standard tricycle gives the system a familiar look, while the display adds visual feedback to provide stimulation during the pedalling exercise.

Portable Weight Gym. The objective of this project was to provide a child sized exercise gym with pulley driven weights and a chinning bar. A portable unit was constructed from PVC pipe which is sturdy and attractive. It can also be easily disassembled for transport to the Center's outreach locations.

Hand and Arm Exercise Systems. Three different hand/arm exercise systems which are attractive to the user and provide stimulation and reward have been designed. One is for hand squeezing and provides an adjustable pressure requirement before a flashing light display is obtained. The therapist is provided with a calibrated pressure gauge and an override switch which allows for triggering the display on the basis of observed effort rather than actual achievement. A second device provides an audible and visual reward for hand extension using any battery operated toy as feedback. The third device provides controlled arm extension exercise with adjustable mechanical resistance and a bell at full extension.

Audible/Visual Stimulation Systems. A variety of devices have been designed which provide audible and/or visual stimulation to the subject. These can be used by the therapist for attention getting and eye tracking , or for training in action-reaction and switch use through simple user switch inputs. One unit is designed for teaching a midline orientation and provides adjustable switch locations requiring selectable use by either or both arms. On this system, various output combinations can be selected consisting of lights, and/or music, and/or a shutter controlled mirror.

Item Selection Devices. Several different item selection devices have been designed for use in speech and occupational therapy. They provide the user with simple switch inputs for selecting one of several words or physical objects that are on display. The selection made is indicated with lights. One version provides a stepping switch system in which a single switch is used to step through the items one at a time. This version simplifies user training and requires minimal motor ability. Another version provides separate switches for each item. A third version requires the manual manipulation of blocks into matching holes with different rewards for each correct placement. Therapist prompt switches are provided in each device.

Floatation Blocks. A system to create custom made floatation blocks for aquatic therapy was developed based on aerosol insulation foam. The rough shape required is fit with a harness and then the foam is expanded into a suitable mold. Following curing, the float can be easily hand finished to the desired shape.

Low Dexterity TV Remote. The remote control unit for a television was modified to provide large button inputs for the limited functions of on/off, and channel up/down. The objective of this design is to provide the young user with a degree of autonomy in watching television and to stimulate the use of switch operated devices.

Lighted Wheel Chair Tray. A wheel chair tray with a translucent surface and self contained, battery operated flourescent lights was constructed to provide localized lighting for visually impaired users.

DEVICE UTILIZATION

As a result of careful project selection by the therapist staff and the engineering team, and closely supervised design and construction, the projects described above have met with great success in terms of their utilization within the Center's programs. The therapists are enthusiastic about access to this resource and the results obtained. This enthusiasm is readily transmitted to the participating students who gain a broad spectrum of experiences ranging from initial conceptualization, through preliminary and final design, construction, and the delivery of working prototypes. In addition, they gain an introduction to rehabilitation engineering which may guide them in their career path.

DEVICE AVAILABILITY

The devices described above are at this time one-of-a-kind items and are not commercially available. However in most cases they could be easily reproduced and plans and instructions for selected items have been provided to the Center and to the parents of the children served. Design details will also be provided to anyone requesting them.

ACKNOWLEDGEMENT

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Development of a Programming Environment for Rehabilitation Robotics

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ABSTRACT

This paper presents an overview of work being conducted towards the development of a programming environment for rehabilitation robotics research and development. This environment is intended to address the issues of standardization, continuity within projects, and collaboration between various robotics research efforts. A summary of the design criteria as well as an overview of the environments' design is presented.

BACKGROUND

The use of robotics in rehabilitation requires a unique set of design criteria [5]. These criteria have their foundation in human-factors concerns which diverge from those found in the standard industrial environment in four areas:

-*safety:* a human person is highly likely to be within the working envelope of the robot, and may well be the object of a specific task.

-*man/machine interaction:* since the robot is an assistive tool, there is need for a high degree of interaction. Further, the user is presumed to be physically disabled and therefore limited in his or her capacity to interact with the system.

-*task complexity/volume:* human activities are usually highly complex and low volume.

-*environment:* the human environment is typically unstructured and mutable.

These criteria call for an effort to create a robot control strategy for rehabilitation robotics. Two major efforts have been made towards the development of a standardized rehabilitation robotics control language: *Calvin* [3] and *CURL* [4].

PROJECT PHILOSOPHY

There are more than a dozen existing projects in the area of rehabilitation robotics. These projects tend to suffer from two common limitations: 1) minimal interaction between research projects and 2) poor continuity within projects when equipment is upgraded or robots are changed [2,6]. The common contributing factor is a lack of standardization.

Standardization can be addressed at either the hardware or software level. Hardware standardization is deemed impractical as no single manipulation aid can serve the wide variety of user and research needs most efficiently [5]. Software standardization can be achieved by development of a robot control language or the implementation of a robot control architecture on an existing language [8]. A robot control language is defined as a means by which programmers can express the operations of a robot and associated activities) [10]. The term *associated activities* is critical to the world of rehabilitation robotics. The system architect who designs and develops a new robot control language will be required to provide interface capabilities for a large number of devices (i.e., input devices, sensors, task planners, etc.) as well as standard language features (i.e., flow control, data type support, etc.). The task is needlessly large.

Imposing a super-set of functions, or architecture, on an existing language avoids the need to develop basic language features and allows the designer of such a system to directly address the robot control issues. If the host language is broadly featured, in high use and well supported, the interface capabilities are built-in and many on-the-market solutions become viable tools.

Standardized robot control is possible because robotic manipulators are essentially six-dimensional systems. The robot library component of the environment (described below) provides standard operations to be performed in this six-dimensional model. Robot specific characteristics are hidden from the user in the lower layers of the library. Further, because no assumptions are made concerning the application, the environment allows for a variety of solutions to any given problem.

A primary goal of the programming environment is to minimize the re-engineering effort required to convert a given application from one robot system to another by eliminating software incompatibility issues. Some application re-engineering may be needed and will be governed by differences in geometry between robot systems.

OVERVIEW OF DESIGN

The proposed Programming Environment consists of a number of related libraries and various utilities.

The Robot Library

The primary component of the Rehabilitation Robotics Programming Environment is the robot control library, which is composed of a three-level structure. At the lowest level is the communications library described below. At the highest level are the library functions themselves. These are defined and described in an accompanying manual and provide control over the designated system in tool, cylindrical, and cartesian coordinate schemes. Additional coordinate schemes can be implemented without expanding the number of functions since the designated scheme is passed as an enumerated argument to the individual functions. In addition, a variety of status functions are provided which allow the program to query the condition of the system. For greater naming flexibility, a series of macros have been defined which utilize specific attributes of a given function and provide greater coding clarity and efficiency.

The link between the robot functions and the communication functions is facilitated, where necessary, by an intermediate level of robot-specific functions. The functions enable the various capabilities of a specific system so as to make them available to the higher level functions. Although these functions will be documented and made available to the programmer, they are not intended to be used in that manner since they will be, by definition, non-standard across other robot systems. Use of them will diminish the portability of applications.

An auxiliary group of functions will be provided with each robot. These will enable the programmer to access features specific to the system they are using (i.e, signal ports, etc.) Once again, applications programmers will be warned in the documentation that these features are non-standard and use of them will affect the portability of their code across robot systems.

Communications Library

This library provides a set of communication functions used by the robot control functions. The default communications medium, provided with the current version of the robot library, provides serial communication. These functions can be replaced by new communications functions of the programmers' own design, so long as the type and argument list of the new functions match that of those being replaced. The robot control library can potentially communicate across any possible link.

Position/Object Data Structures

The position/object data structures module is a supplementary library which is completely robot independent. The library will function as an environment-specific database with specific object management capabilities. This work is patterned on the work done by Gosine [4] but anticipates expansion on the model and proposes to remove it from the context of a specific application.

User Input Drivers

Given the wide diversity of population and disability being addressed and researched, it is critical that this programming environment does *not* target a single input device as the primary and preferred method of interaction with the system. Experience and a review of the literature demonstrate that systems are being used with everything form a single switch input to a complicated analog and/or speech interface. The input device library will provide access to the robot through a variety of possible devices and allow for devices to be exchanged in a modular fashion.

Current Hardware/Software Use

The initial robot library is being implemented on the RTX from UMI [9], due to its high degree of use within the field. The standard language chosen for use in developing the architecture is C [7]. C provides the high degree of flexibility, low level capabilities, portability, and general language acceptability needed in a host language. The initial code is being developed using the Microsoft C Compiler (version 5.1). The operating system of choice is MS-DOS running on a PC/AT/386 or compatible system.

FUTURE DIRECTIONS

The results of a survey, currently being conducted by this Robotics Research Program, will be used to target additional features deemed necessary by the research community in general. These new features will be included in the design criteria for the Programming Environment Project. With the development of CURL [4] and its continued improvement, the need for an interpreter would seem to have been met. Plans are currently being made for the use of the robot library as the robot control drivers in CURL.

Evaluation of the programming environment will be undertaken at several levels. This will include expansion into other robot systems, local evaluation and review of the software by both primary and secondary external sites. The evaluation methodology is derived from the one developed by Foulds et al [1] for software projects at the REC on Augmentative Communication.

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MOUSETRAP:

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SOFTWARE FOR A VOICE AND HEAD OPERATED QUADRIPLEGIC CAD WORKSTATION MAY FIND ADDITIONAL UTILITY AS PART OF A CAD BASED, FRIENDLY USER INTERFACE FOR A PERSONAL ROBOTIC ARM.

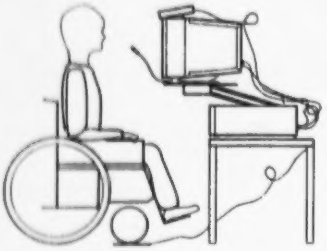
At Washington State University's School of Architecture, a voice and head operated CAD workstation has been developed for quadriplegics. Field testing benchmarks with popular "off the shelf" software have indicated drafting productivity frequently equals or exceeds manual drafting of the same documents. Several "off the shelf" software packages used in this context may provide a flexible and friendly user interface for control of a personal robotic arm.

BACKGROUND As an architectural educator, teaching computer aided design and having friends who were severely physically handicapped, I became curious if a high quadriplegic could gain control of our CAD software. In late 1984, my CAD students duct-taped me to a wheel chair (I had no CAD trained quadriplegic available) and rolled me in front of a CAD terminal to test our first prototype configuration of a voice and head controlled CAD workstation. Early benchmarks indicated that CAD drafting productivity could reach 70% above manual drafting of the same architectural drawings.

Based on this early success, and with Easter Seal Research Foundation funding, we came to several conclusions that would be important if we were to support quadriplegics in our 5 year professional degree program and in the field:

- The hardware must be common, "off the shelf" equipment.
- Special hardware should be minimized. Most customizing should be done in software.
- The workstation (for educational use) should be configured for attendant free use by more than one student.
- Telephone functions should be integrated. (This is of particular importance in the office and for residential use).

Our current workstation configuration is a "standard" PC in most respects, other than the addition of a speech recognition system and the "NOD" optical head position sensing device. (fig.1)



(fig.1)

WORKSTATION OPERATION The workstation is powered up when the wheelchair bound user approaches the system. A gooseneck noise cancelling microphone, speaker box and monitor are mounted on a standard monitor arm in such a way as to permit the user to wheel into the operating position. A light weight wireless headset may be worn for a more private dialog with the machine, and telephone system. The "NOD" head position detector tracks the position of a small patch of special reflective tape, placed on the nosebridge of glasses. If the telephone rings, the user can speak a couple of pre-trained words to activate the telephone answer functions. The work in progress remains "frozen", awaiting the termination of the call, the "hang-up" and confirmation words. Then the session returns to the work at hand.

The primary application software being operated is AutoCAD: The micro-computer industry standard, design and drafting program for anyone who draws. The workstation configuration will also run most other popular office automation software. The highest productivity is associated with programs that use a mouse.

HEAD MOVEMENT MOUSE EMULATION We have used a unique device for detecting head position. The "NOD" by Millenium Computer Corporation ($495) is an infrared device that sends and receives pulsed light. The "NOD" is a small box, perched on top of the PC monitor. When a small piece of reflective material is positioned in front of the box, the light from the LED's bounce back to the sensors, identifying the location of the reflection.

CUSTOM SOFTWARE The WSU developed software configures the NOD, and maps the coordinates into a standard EGA screen. It operates in tandem with a standard Microsoft mouse. Both devices are active, with the NOD's coordinates dominating, when reflector movement is sensed. We program the NOD (tell it how to behave), accept coordinates from a serial port and control a standard mouse driver. Special commands from the voice system represent words associated with mouse buttons. We then have the full range of "point and pick" functions needed for fast and efficient control of PC graphics applications.

MTRAP.EXE (mouse trap) is our program which does those functions. We co-exist in user RAM along with the voice system driver, and standard mouse driver, as a TSR (terminate and stay resident) program. We use a standard MS Mouse, to permit a non-handicapped user to use the system or quickly assist in pointing if needed. We "trap the mouse" coordinates when the cursor needs updating from the NOD, and replace them with our own, then return control to the application program. We also "filter keyboard data from the voice system, before it goes to the keyboard buffer, and look for special ASCII characters (as defined by the user) which represent mouse buttons.

APPLICATIONS The workstations prime mandate has been to run AutoCAD which has become the "standard" of the full function microcomputer CAD programs. Smaller, more specialized programs have also been successfully operated. However, AutoCAD's menu bar and pull-down windows make it particularly well suited for minimizing voice commands; most operations are carried out by pointing to the menu and speaking the left mouse button "pick" word. We use terminal emulators for access to applications running on external host computers.

Many popular programs (both graphic and alpha oriented) are now acquiring mouse driven icon interfaces, for which this workstation configuration is particularly well suited. The more use of the mouse, the less crowded the voice vocabulary has to be

The price for a complete system (including AutoCAD, a speech recognition system, and the NOD), will vary from a base of about $10,000 up to, and over $20,000 depending upon the performance requirements and application software used.

CAD PRODUCTIVITY COULD INCLUDE ROBOTIC ARM HUMAN INTERFACE Based on our success with the CAD workstation, and given the configuration of existing PC controlled personal robotic arms, a marriage seems inevitable. Picture if you will, a 3D drawing of a robotic arm work cell appearing on the workstation VGA screen. The user asks for a software manual to be retrieved and placed on a viewing stand. The proposed arm path is then superimposed on the drawing for inspection. If path is observed to be inadequate for the task desired, and an edited path is proposed and visualized. A verbal command and confirmation is then issued and the drawing is then translated into movement macros and executed.

I see major areas of compatibilities between these existing technologies to be:

- The commercial offering of a personal robotic arm and workstation, using a 80386 CPU platform.
- The need for learning only one primary visual application for robotic interface and CAD tasks, aided by high productivity "point and pick" graphic screen functions.
- The popularity, programmability, versatility, and modularity of AutoCAD. Well established documentation and user support provide a superior software development environment.
- The potential for one 80386 based CPU as the host for CAD application and robotic controller.
- The potential for application and controller multitasking under the OS/2 operating environment.

CONCLUSION We live in a world of increasingly friendly and sophisticated office automation, most of it built on the DOS based, personal computer. We are also discovering the productivity potential of our nations handicapped, when given proper access to the tools of the automated office. A personal robotic arm controlled by a popular, sophisticated, 3D CAD product via voice and head movement could be a symbiotic integration of existing technology that could be serving the quadriplegic community in the short term. I look forward to receiving "the NOD" to develop such a link.

SUPPORT The Easter Seal Research Foundation

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USER SELECTION CRITERIA FOR A VOICE ACTIVATED ROBOTIC WORK CELL

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ABSTRACT

It is essential that rehabilitation professionals learn how to screen potential candidates for robotic assistive devices to ensure a correct human-machine interface so that the individual can benefit from the technology and succeed. This paper will discuss how a team of occupational therapists developed screening criteria for determining first priority users of the Prab Voice Command robotic workstation.

INTRODUCTION

The use of robotic assistive devices can return severely physically disabled individuals to an independent work setting by providing user control of the environment, decreased dependence on attendant care, and also improve quality of life. There is a strong need for training of rehabilitation professionals in the use and application of robotic assistive devices in order to appropriately select and train the severely physically disabled for vocational placement. The Department of Occupational Therapy at Western Michigan University is currently involved in a collaborative relationship with a robotics firm that has developed a voice activated robotic work cell that enables high level quadriplegics (C_1-C_4) to use a microprocessor based work station containing a stationary robotic arm to do office management functions. These functions include operation of accounting systems, word processing, and telephone management, including telemarketing.

In looking at any assistive technology, there must be a careful evaluation of who would benefit the most in addition to what skills would the individual need to operate the technology in an efficient and effective manner. Without a careful match between human and machine, the technology is often discarded. A model of determining human machine interface considerations in a vocational environment, developed at the Palo Alto Veterans Administration Medical Center (1), was used to determine a criteria for selection of users.

METHODOLOGY

Disabled User

Screening factors include consistent voice recognition, including considerations for respirator dependent individuals; head and neck control with or without support for viewing the monitor and robotic arm; positioning for posture and pressure relief; tolerance and fatigue factors; vision; health status; cognition; work habits, behaviors, and interpersonal skills necessary for securing and maintaining employment.

Robotic Work Cell

Screening factors include the following: 1) accessibility of the robot to the user from various degrees of reclined seating positions (erect to horizontal); 2) how to access any activities that are not controlled by voice (mouthstick or switches); and 3) safety factors such as no physical linkage between the robotic arm and user, including awareness of how to seek assistance if needed for safe operation of the unit.

Vocational Environment

Screening factors include space requirements and the maneuverability of powered mobility within the work cell. Lighting and temperature factors are considered because of the difficulties in body temperature control in the high level quadriplegic. Additional equipment and supplies needed to complete the job are considered in addition to the attitude of fellow employees.

CONCLUSION

The user selection screening criteria was designed to give the rehabilitation professional who is involved with training of robotic assistive technology, a method of determining candidates that would have the greatest potential for success using technology such as the Prab Voice Command robotic work cell. A data collection system has been designed to determine if the tool is useful to rehabilitation professionals in determining the strongest candidates for use of the voice-activated work cell.

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INFORMATION DISSEMINATION REGARDING SUCCESSFUL PROGRAMS, COMPONENTS AND PRACTICES IN ASSISTIVE TECHNOLOGY SERVICES

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Sharing Methods and Applications in Rehabilitation Technology

ABSTRACT

The S.M.A.R.T. Exchange is a network designed to promote the widespread use of validated assistive technology practices and successful programs in selected priority areas within Rehabilitation Services Administration Region IV. The primary focus is to improve the delivery of assistive technology services via a multidimensional information exchange and technical assistance system, to benefit persons within all age groups and disabilities. The S.M.A.R.T. Exchange is committed to reaching out to persons with disabilities, parents, and professionals who recognize the power of technology to change the quality of life for individuals, young and old, in the home, classroom, workplace and the community.

BACKGROUND

The S.M.A.R.T. Exchange, housed within IBM's National Support Center For Persons With Disabilities, located in Atlanta, Georgia, resides within the geographic center of the southeastern region. This location is also the regional headquarters for the Rehabilitation Services Administration, which enables The S.M.A.R.T. Exchange to avail itself of existing local information networks and experts interested in providing assistive technology services. The decision to locate daily operations at the IBM National Support Center For Persons With Disabilities represents a unique public/private sector partnership, thus providing the project with access to its extensive technology resources and experts. This relationship has proven to be mutually beneficial and should continue to grow as successful programs, practices and components are identified and disseminated throughout the southeastern region.

INTRODUCTION

The S.M.A.R.T. Exchange identifies successful organizations within Region IV that utilize effective assistive technology practices within the services areas of early intervention/preschool, education, transition, employment, independent living and recreation & leisure programs. These successful organizations emphasize the use of technology related assistance in the areas of positioning and mobility, augmentative communication, computer access, adaptive toys/games and adaptive environments. The identification and selection of practices deemed successful are made in accordance with a set of five quality indicators developed by the project staff and a Regional Advisory Board of distinguished professionals, parents and individuals with disabilities from RSA Region IV.

Technical assistance is provided to the selected organizations by regional, national and project experts in order to facilitate the adoption of their successful programs, components and practices to people interested in developing or modifying their existing services.

The S.M.A.R.T. Exchange disseminates information pertaining to successful practices and training opportunities via newsletters, published resource and expert consultant guides, teleconferences and sponsorship of regional technology conferences.

DISCUSSION

The Quality Indicators

A set of quality indicators were developed to evaluate an organization's successful implementation of technology related services. These quality indicators were comprised of a rationale and specific criteria which focus upon five target areas including philosophical framework, consumer/family participation, comprehensive service delivery model, funding and consumer satisfaction.

The Selection Process

Enthusiasm and motivation for participation in this project was initially generated through regional dissemination of a colorful poster announcing the project's formation. A program application was developed to assure a standardized evaluation of all participating organizations and then disseminated regionally. This solicited specific information pertaining to the organization's strengths, barriers to becoming more successful, significant consumer outcomes, flexibility, responsiveness to advances in technology and need for technical assistance.

Applications were reviewed by the project staff and recommendations were made regarding applicants warranting further review. Telephone interviews were conducted, using a standardized set of questions, to further narrow the selection of candidates. Fifteen candidates were then selected for on-site review conducted by a team comprised of project staff and regional advisory board members. Following these on-site visits, twelve organizations were selected for their successful program practices in the implementation of technology related services to individuals with disabilities. Potential adopter sites were drawn from the pool of applicants who were not selected, but demonstrated promising components in their use of assistive technology.

Technical Assistance

Technical assistance is a process designed to facilitate the exchange of information between identified successful programs and potential adopter sites, for the purpose of developing, modifying and/or expanding their technology related services. Written agreements between The S.M.A.R.T. Exchange and the identified successful organizations were developed to facilitate and more clearly define the technical assistance to be provided to the adopter sites in their replication efforts. These agreements were based upon the individual needs stated by all the participating organizations.

Replication efforts often fail due to the increased responsibilities and costs involved on the part of the organizations providing technical assistance. Therefore, The S.M.A.R.T. Exchange offered a variety of incentives to identified participants, including financial incentives of up to $5,000 per site, technical assistance from local, regional and national consultants, program recognition via project publications, journal and newspaper articles and appearances at regional conferences. Training stipends were also made available for staff of adopter sites to attend regional training institutes conducted by the identified successful organizations.

Dissemination

The project's dissemination methods have been designed to stimulate the interest of program administrators and staff, professionals, parents and consumers in all eight states. Attracting the attention of the target audience through presentations at annual meetings and regional conferences, electronic boards, training institutes and teleconferences, will increase the project's potential impact.

CONCLUSION

The need for information diffusion in the area of assistive technology has been documented extensively in recent years. As each organization grapples with planning and implementing cost-effective technology related service delivery systems, they need to develop effective solutions to the problems of consumer demand, funding availability, qualified professionals and keeping pace with technology development and innovation. In response to this, The S.M.A.R.T. Exchange has documented proven programs, practices and components for the implementation of assistive technology services throughout the southeastern region of the United States.

ACKNOWLEDGMENTS

The S.M.A.R.T. Exchange is funded through a grant by NIDRR (#H133D80014) and UCPA. For more information, contact The S.M.A.R.T. Exchange, P.O. Box 724704, Atlanta, GA 30339 or call (404) 238-4568.

FACILITATING INFORMATION EXCHANGE IN THE AREA OF FUNCTIONAL ELECTRICAL STIMULATION

P3.22

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ABSTRACT

Functional electrical stimulation (FES), as a rehabilitation technology, shows great potential for increasing the ability of persons with central nervous system impairments to live more independently. If utilization of FES by disabled individuals is to become widespread, the exchange of FES-related information between disabled consumers, researchers, medical care providers, manufacturers, service providers and third party payors must be smooth and complete. The Rehabilitation Engineering Center (REC) for FES at Case Western Reserve University has established the F.E.S. Information Center to facilitate this information exchange process.

MISSION

The F.E.S. Information Center was established in response to the NIDRR mandate for provision of an information dissemination program in each of its RECs. The mission of the F.E.S. Information Center is to provide a central and uniform collection of information relating to the FES field and to provide appropriate and efficient dissemination of such information to each of its clients.

The F.E.S. Information Center will direct its planning activities toward achievement of the following goals:

1. To provide information that is accurate, timely, and objective;
2. To increase awareness, on a national level, of the status of FES research and commercialization;
3. To respond to changing information needs in the field of FES.

ORGANIZATION

Location

The F.E.S. Information Center is located in the offices of Services for Independent Living, Inc., a nonprofit Cleveland area organization serving people with disabilities, which is a member of the National Council for Independent Living. This organization offers the F.E.S. Information Center expertise in information brokerage for people with disabilities, a national network for communicating with potential FES consumers, and an environment which is free of parochial bias in which to evaluate FES technology in the framework of independent living. The CWRU community provides the F.E.S. Information Center with readily available clinical and technical expertise in the FES field.

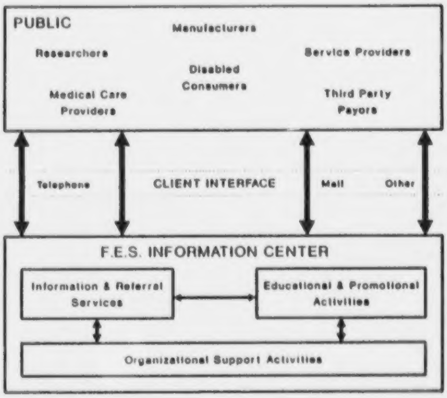

Figure 1. Organizational Structure

Structure

Figure 1 illustrates the division of the F.E.S. Information Center into three functional areas: Operational Support Activities, Information and Referral Services, and Educational and Promotional Activities. This figure also shows the populations that have been targeted as potential Information Center clientele and indicates that a multi-channel interface exists between the Information Center and the public.

Operational Support Activities refer to general office activities (purchasing, mailings) that keep the Information Center operating on a daily basis. Included in this area is the ongoing education of the staff in the areas of FES and information technology, and the regular evaluation of F.E.S. Information Center services.

Information and Referral (I&R) Services are a major component of the Information Center programs. Activities in this area revolve around the support and the processing of information inquiries made to the Information Center by its clientele. The activities include maintenance of the physical materials which make up the various collections of the F.E.S. Information Center Library, maintenance of the computerized database which indexes those materials, and the handling of information requests.

Educational and Promotional Activities serve to enhance the I&R function of the Information Center as well as to generally increase public awareness regarding FES. Included in this area are the development of in-house publications and educational presentations, the support of special interest forums, research into improved methods for disseminating information in the area of FES, and promotion of Information Center services.

OPERATIONS

Pilot Phase

The F.E.S. Information Center is currently operating under pilot phase conditions, characterized by limited interaction with primarily local area clientele. Clientele access Information Center services via local or 1-800 phone service. During this phase the Information Center can evaluate and respond to the information needs of its clientele on a small scale basis, and at the same time direct a major effort towards specification and development of its services.

Several important activities will be completed during this phase:

1. Design and development of standards for handling the materials in the F.E.S. Information Center's library including: collection strategy, acquisition methods, inclusion criteria, cataloging and classification, and lending and browsing procedures;
2. Design, development, and data entry of a database reflecting the contents of the F.E.S. Information Center library. The database will support automatic search and retrieval of information by staff in response to inquiries;
3. Design and development of an information system for logging and tracking inquiries to the F.E.S. Information Center;
4. Development and production of an FES Information Packet which will include: a list of common questions and answers on FES techniques, a layperson's glossary on FES, a quick review on the status of FES technology, and a bibliography of informative publications.

Also during this phase the F.E.S. Information Center will conduct specially targeted national surveys of its clientele to assess their information needs. The Information Center will begin compilation of a directory of FES research programs, and will begin to establish a network of experts for referral on matters related to widespread utilization of FES by persons with disabilities.

Expansion Phase

Movement into this phase of operation will occur when the resources and materials of the F.E.S. Information Center are available to its staff in a readily accessible format. Access to Information Center services will continue to be primarily via local and 1-800 phone service. This phase will be marked by a national and international promotion of F.E.S. Information Center services.

During this phase, F.E.S. Information Center resources will be used for processing incoming inquiries, ongoing maintenance of the F.E.S. Information Center library and database, and generation of in-house publications such as review papers and directories.

Focused activities during this period will include:

1. Development of systematic evaluation methods for measuring the effectiveness of F.E.S. Information Center services from both the organization's and the client's point of view;
2. Design, development, and implementation of a process for matching potential FES candidates to participating FES research programs;
3. Regular production of a F.E.S. Information Center newsletter;
4. Investigation into providing on-line or on-site access of the F.E.S. Information Center database;
5. Development of a forum for end-users of FES technology to share ideas, concerns, and experiences.

The F.E.S. Information Center will actively cooperate with other agencies involved in the dissemination of information on rehabilitation technologies to develop centralized and standard access methods and to reduce information redundancies.

CONCLUSION

The F.E.S. Information Center is designed to be a responsive organization. As FES evolves from a research-based technology into a commercially available rehabilitation product, the Information Center is prepared to adapt its services to the changing information needs of the public. No amount of planning and preparation for services, however, can be a substitute for quality information. The F.E.S. Information Center relies on the cooperation of experts in the FES research community to make current information available. In return for this expertise, the F.E.S. Information Center will strive to provide quality services to the inquiring public, to continually evaluate and update those services, and to respond to the evolutionary needs of the FES research community.

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COMMON OBJECT TEST: A FUNCTIONAL ASSESSMENT FOR QUADRIPLEGIC PATIENTS USING AN F.N.S. HAND SYSTEM

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ABSTRACT

Case Western Reserve University has developed and is using a Functional Neuromuscular Stimulation (FNS) system for restoration of hand function in C5 & C6 spinal cord injured patients. We have developed a functional assessment tool, the common object test (COT), to evaluate functional outcomes that are specified goals of the system. These specific goals include increasing independent function by 1) decreasing the need for attendant care, 2) increasing the ability to use unmodified objects, and 3) increasing the number of activities a patient is able to perform. Assessment of patients is proceeding.

INTRODUCTION

The purpose of the COT is to: 1) compare a patient's hand function with FNS and without FNS by assessing performance during activities of daily living, 2) evaluate how a patient actually performs these activities within his unique environment and 3) determine a patient's personal satisfaction with the FNS hand system.

METHODOLOGY

The following terms are used to describe the test:

1. *System*: any modifications of the primary hand used to perform the activity. Patients are always tested with two systems (a) the FNS hand grasp system, and (b) the non-FNS system, which is the best alternative to FNS and includes any appropriate orthoses.

2. *Activity*: an activity of daily living that is characterized by an end result, e.g., drinking or eating, but does not specify the way the end result is accomplished.

3. *Method*: a specific way of performing an activity, e.g., eating by stabbing food with a fork. More than one method may be tested for each activity.

4. *Phase*: each method used to accomplish an activity is divided into phases which describe the individual steps that are performed during an activity, e.g., acquiring, lifting, lowering and releasing an object.

5. *Independence*: a composite score that describes how independently a patient performs an activity using a particular method. The independence score is described in detail below.

Any adaptive equipment or orthoses necessary for specific activities are determined for each patient. The patients are trained during the test to perform an activity with the defined method at their highest comfortable level of independence.

SCORING

The score is judged from several performances of each activity and method. The patient is scored on 1) independence of performance, 2) quality of performance, 3) preference, 4) frequency of an activity, 5) frequency of method, 6) frequency of method at the observed level of independence for both systems, and 7) importance of the activity to the patient.

1. *Independence Score*: Independence is rated on a 4-point scale. "Self assistance" (SA) is using a part of the body other than the tested hand to assist in completing the activity. "Physical assistance" (PA) is assistance from an attendant. "Adaptive equipment" (AE) includes any modifications of the test object, but does not include an orthotic device (which is part of the non-FNS system). "Independent" (IND) is performing the activity with the tested hand, without PA, SA, or AE. In ascending order of independence, the 4 ratings are PA, SA, AE and IND.

   Each phase of a particular method is rated separately. For example, a patient may require physical assistance to acquire an object, but not to lift or lower the object. Similarly, if a patient uses a piece of adaptive equipment, the patient is only scored "AE" during the phases where the equipment is actually required. Each phase is scored regardless of the score for other phases. "Independence" or "Level of Independence" for each method is defined as the aggregate of independence ratings across all phases.

2. *Quality Score*: The therapist compares the quality of performance using the FNS and non-FNS systems. The comparison is based on the outcome of the

activity, and not on the level of independence. A three point scale is used:
+ = The quality is improved with FNS
0 = The quality is the same with FNS and without
- = The quality is worse with FNS than without FNS
This is evaluated to determine if quality is effected by using either system, e.g., the quality of drinking from a glass is determined by how much water is spilled, regardless of how independently the method is executed.

3. *Preference Score*: The patient identifies which system he prefers for each method. The choice will take into account the level of independence, quality of performance and any other factors that are significant to the patient. The therapist asks the patient, "If you had to perform this activity, (with this method), would you prefer to do it with the FNS system or the non-FNS system?" This is used to assist in determine patient satisfaction.

4. *Frequency of Activity*: The therapist asks the patient "How often is (this activity) performed outside of the lab, regardless of (the method)?" This is only scored one time if the activity has different methods (e.g., the activity of eating has several methods, including using utensils and using fingers). The frequency is rated on a five-point scale: VF = very frequently, F = frequently, S = sometimes, I = infrequently, VI = very infrequently. Frequency of Activity, Method and Independence are used together to confirm appropriateness of selected activities and determine patient functional behavior outside of the laboratory.

5. *Frequency of Method*: The therapists asks the patient "Of the times (the activity) is performed, how often is it performed by (the method tested in the laboratory), regardless of independence?" The frequency is rated on 5-point scale: 0-20%+, 20-40%+, 40-60%+, 60-80%+, 80-100%.

6. *Frequency of Independence*: The therapist asks the patient, "Of the times (the activity) is performed by (the laboratory method), is it performed with the same level of independence as used during the test for the (FNS and non-FNS system)?" The frequency is rated on the 5-point % scale described above.

7. *Importance Rating*: The therapist asks the patient, "How important is this activity to you?" The importance is rated on a four point scale: VI = very important, IMP = important, SI = somewhat important, NI = not important. This is asked because some activities may have high frequency but low importance and other activities may have low frequency but may be very important.

ACTIVITIES

The activities evaluated in the COT have been chosen by 1) reviewing published literature on upper extremity tests, documenting activities tested, and selecting the most frequently tested hand activities, 2) reviewing published literature on ADL tests, listing the most frequently tested activities and selecting the most frequent activities that would be affected by improved hand function, 3) reviewing several hand tests used in clinical practice that were applied to patients. These tests are useful with a variety of diagnoses but used a scoring system that penalized quadriplegic patients or used simulated activities that did not represent actual functioning for quadriplegics, 4) reviewing the goals for C4-C7 quadriplegic patients in published therapy protocols, and listing activities that are viewed as important in training for these patients and determining which are hand activities, and 5) combining these lists and reducing them by eliminating all activities that are bilateral, gender dependent, or age dependent. Bilateral and gender dependent tasks although very important and included in a complete list, could not be performed consistently across patients.

CONCLUSIONS

We have developed an extensive functional assessment tool which is being used with patients and which we believe will assess not only what patients are capable of performing in the laboratory, but begin to identify how patients incorporate this device into their daily life, and document their personal satisfaction with it. This data is also being used in collaboration with an internal monitoring device. This device documents how long the system is in active use, and what the mode transitions are. Together, this information will be used 1) to identify if the system is meeting its stated goals, 2) to monitor patient programs and provide feedback to the patients on changes in their functional abilities, 3) to identify and forecast success candidates for implementation and after sufficient data is collected from this test and from personality evaluations.

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P3.24

TECHNOLOGY TRANSFER OF AN UPPER EXTREMITY FUNCTIONAL NEUROMUSCULAR STIMULATION PROGRAM

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ABSTRACT

A technology transfer program has been established to facilitate the delivery of Functional Neuromuscular Stimulation (FNS) hand systems to remote sites for efficacy and evaluation studies. Protocols, procedures and equipment needed for implementation and evaluation of a Functional Neuromuscular Stimulation Program for the restoration of hand function were transferred from the Case Western Reserve University (CWRU) Rehabilitation Engineering Center (REC) to four other North American centers. These systems are used with patients who have sustained C5/C6 complete spinal cord injuries. The technology was transferred for the implementation of hand systems using percutaneous electrodes and externally powered and controlled stimulation units. The four remote centers involved are: The University of Alberta, Edmonton, Alberta, Canada; The Hugh MacMillan Medical Center, Toronto, Canada; The Shriners Hospital, Philadelphia, Pennsylvania; and The Rancho Rehabilitation Engineering Center, Downey, California. Presently, five patients have been implemented with the hand systems with an anticipated total population of 15 patients participating in the program.

INTRODUCTION

The purpose of this technology transfer program is to:

1. Test the efficacy of the CWRU hand grasp restoration program at remote sites.
2. Establish protocols and standards for implementing the hand systems.
3. Implement evaluation protocols to test the levels of enhancement that patients are achieving by utilizing the hand systems.
4. Develop a communications network among the transfer centers that will use their data as a feedback mechanism to enhance and modify the program.
5. Initiate a platform for the future transfer of an implantable neuroprosthetic stimulator device.

The FNS Hand Grasp Systems developed by this REC use percutaneous electrodes implanted into the paralyzed upper extremity muscles of C5-C6 spinal cord injury patients. The electrodes are stimulated using a portable 16 channel stimulation unit. The stimulation to individual muscles is programmed based on a command mapping scheme to develop two basic hand grasps (lateral and palmar prehension/release). The patient controls the position and force of the hand by moving his contralateral shoulder using either protraction/retraction or elevation/depression. The motion of his shoulder is transduced by a miniature, dual axis proportional hall effect transducer.

The Clinical Centers were chosen by CWRU based on their clinical expertise in the area of rehabilitation medicine, the resources available at the center to implement the technology and the resources available to locate and support an adequate patient population. The technology will be transferred in stages over a two to five year period. During the first stage, the centers are trained at CWRU, receiving the equipment and supplies necessary to implement new subjects. During subsequent stages the centers begin implementing patients and evaluating the systems.

Over the course of two years a total of approximately 15 patients will be implemented and evaluated at the five centers.

PROCEDURE

A three day training seminar was conducted in Cleveland, Ohio to train members from the other participating centers in the implementation, evaluation and maintenance of an Upper Extremity Functional Neuromuscular Stimulation Program. Each center sent a two member team consisting of a clinician and a rehabilitation engineer.

Prior to the seminar, a complete notebook was generated with full documentation of all the procedures involved in the technology transfer. During the seminar, each area addressed in the notebook was presented by a qualified person from the CWRU REC. Some of the sessions were presented using live patients. Other sections were demonstrated using video tapes, slides and other educational media. Trainees actively participated whenever possible.

The following procedures and techniques were explained and documented:

- Clinical Procedures
    - Candidate Selection
    - Patient Education and Consent
    - Intervention Prior to Implantation of Electrodes
    - Implantation of Percutaneous Electrodes
    - Hand Grasp Development
    - Stimulation and Control Parameter Programming
    - Shoulder Control Parameter Setup
    - Functional Training and Evaluation
    - Evaluation Techniques
        - Standardized Object Test
        - Common Object Test
        - Patient Survey
    - Monitoring Activities
- Patient Notebook and Forms
- Hardware and Software
    - System Overview
    - Stimulation Unit
    - Cables
    - User System Operation
    - Peripheral Support Devices
    - Investigator System Operation
    - Maintenance and Troubleshooting
- Supplies

The following hardware and software was transferred to the participating centers:

- Percutaneous Electrodes
- Stimulation Units
- Shoulder Position Transducers
- Peripheral Support Devices
    - Controller Box
    - Stimulus Waveform Monitor
    - Load Device
    - Power Supply Monitor
    - Single Channel Stimulator Monitor
- Surface Connectors for Percutaneous Interface

RESULTS

At the time of this abstract, the initial stage of transferring the technology has been completed. The remote centers sent representatives to the CWRU center to be trained. All centers received full documentation for implementation and evaluation. Two of the centers received all the equipment and supplies necessary to begin the program. The other two centers will be receiving the required equipment within 3 months as designated in our research timeline. The initial transfer of information was deemed a success by those attending the seminar.

FOLLOW-UP

Each of the centers will admit their own patients into their FNS program and follow the admission and implementation procedures outlined by the CWRU REC. Each center will then collect evaluation and functional data for each of the patients at specified intervals and send this information to the CWRU REC to be evaluated in conjunction with the data from each of the other centers.

CONCLUSIONS

The utilization of FNS neuroprosthetic systems for restoration of hand function for persons with quadriplegic disabilities has been demonstrated to be an effective means to enhance functional independence. We have implemented 32 patients over the past 10 years and are optimistic about transferring the technology to implement and evaluate these systems with patients at remote sites. We have undergone a rigorous introspective approach towards documenting and standardizing our practices of implementation and evaluation. These protocols will continue to evolve with feedback from our own program and that of the remote centers.

ACKNOWLEDGMENTS

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P3.25

A RETROSPECTIVE ANALYSIS OF PERCUTANEOUS INTRAMUSCULAR ELECTRODES FOR FUNCTIONAL NEUROMUSCULAR STIMULATION IN QUADRIPLEGIC SUBJECTS

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ABSTRACT

Chronically indwelling percutaneous intramuscular electrodes have been successfully used to electrically activate paralyzed muscles for many years. A retrospective evaluation of the performance of the present electrode design demonstrates the viability of this technique for chronic use in functional neuromuscular stimulation. The study involved 572 electrodes implanted in 32 patients over an 11 year period and updates our previous report (4). An analysis of the electrode lifetimes under various conditions and the causes of electrode failure allows a prediction of future electrode survival rates and suggests design improvements which can be used in permanently implanted electrodes.

INTRODUCTION

Functional neuromuscular stimulation (FNS) of the upper extremity through chronically indwelling percutaneous intramuscular electrodes is used to restore functional grasps to the paralyzed hand of C5/C6 level quadriplegics (2,3). The percutaneous intramuscular electrode allows repeatable, selective activation of desired muscles without eliciting an uncomfortable sensation. The reliability of the electrode is critical in determining the overall effectiveness of the FNS system.

METHODS

In the past eleven years, studies have been performed on 32 spinal cord injury patients using percutaneous intramuscular electrodes for upper extremity functional neuromuscular stimulation. These individuals are injured at the C5/C6 level, retaining some arm and wrist control, but no hand or finger function.

Electrode Description. Two types of percutaneous intramuscular electrode have been utilized by our group since 1978. Most of the electrodes (86%) consist of ten type-316 stainless steel wires, organized into two five-wire strands and insulated with Teflon (Cooner Wire Co.). Each wire is 25 um in diameter, with an insulated cable diameter of 250 um. Several other electrodes (13%) were manufactured from seven type-316 stainless steel wires, organized into a single seven-wire strand and insulated with Teflon (California Fine Wire Co.). Each wire is 46 um in diameter, with an insulated cable diameter of 250 um. Both cable types are wound into helical configurations with 10 mm of the insulation removed at one end to form the stimulating surface (1), resulting in an estimated stimulating surface area of 10 mm^2. The deinsulated tip is bent back to form a 2 mm barb. Silastic (MDX-4210) is placed at the insulated/deinsulated junction to taper the stress concentration. The resulting outer diameter of the coils is 580 um, thus allowing the electrode to be placed in the lumen of a 19-gauge thin-wall hypodermic needle. The electrode barb remains outside the needle to help anchor the electrode at the time of implantation. The electrodes are then sterilized with ethylene-oxide in preparation for implantation.

Implantation Procedure. The muscles required to synthesize functional grasp patterns in quadriplegic individuals can be categorized into six groups: finger flexors, finger extensors, thumb flexors, thumb extensors, thumb abductor, and thumb adductor. Implantation of these muscles is approached from two insertion sites; the distal dorsal surface of the forearm for the extensors and thumb adductor, and the distal volar surface of the forearm for the remaining muscles. Prior to implantation, the selected muscle is identified by palpation, and an attempt is made to stimulate it with surface electrodes. The needle, containing the electrode, is removed from its sterile package and is inserted through the skin. A low frequency stimulus is passed through the needle, allowing the contractile response to be monitored as the needle is advanced. When the desired response is achieved, pressure is applied to the muscle belly as the needle is withdrawn. The barb on the end of the electrode hooks into the muscle, holding the electrode in place. There is usually no bleeding, but if it does occur, it can easily be controlled by applying pressure to the skin site. Anesthetic agents are generally not used, but lidocaine is occasionally administered. After removing the needle, stimulation is applied to the electrode to ascertain whether the desired contractile response was achieved. Approximately 80% of the electrodes were positioned properly and were retained using this method. The entire insertion procedure for a single electrode is approximately ten minutes. Once a functional set of electrodes has been implanted, each electrode lead is inserted into a plastic connector which is taped to the skin over the implant site. This connector provides protection for the percutaneous electrodes and allows easy electrical connections by acting as a junction box. A multiple-channel cable from the external stimulator is inserted into the opposite end of the connector.

Electrode Assessment. The functional status of each electrode was monitored by regularly measuring the stimulus threshold, the electrode impedance, and the force recruitment properties. The stimulus threshold is the stimulus pulse-width which first elicits an observable contraction. Force recruitment characteristics, [the relationship between the system input (the stimulus) and the output (force)] were measured by placing a force transducer against either the fingers or thumb and applying a one second burst of stimuli to the muscle.

At each evaluation session, based on the above monitoring techniques, electrodes were determined to be either functional or non-functional. Those that were non-functional were either broken or no longer produced the desired contractile response. Broken electrodes were detected by a large increase in impedance, frequently accompanied by an alteration in the muscle excited and occasionally by the presence of sensation during stimulation (subjects rarely experience sensation from intact electrodes). The pertinent information for each electrode that was implanted from 1978-1988 was entered into a database, allowing computerized analysis of the effect of any variation in manufacturing or implantation techniques. With the use of this database, a statistical analysis of the electrode survival rates under various conditions was performed.

RESULTS

Of the 572 multifilament percutaneous intramuscular electrodes implanted between January 1, 1978 and December 31, 1988, 418 have been removed. The reasons for electrode removal were divided into ten categories, as shown in Table 1. Electrodes that were fractured, nonfunctional, or caused adverse sensation were considered to be failed electrodes. These accounted for 155 (37%) of the 418 removed electrodes. The rest of the removed electrodes (63%) were functional at removal and had no mechanical or functional failure.

Table 1 - Electrode Removal Reasons

Removal Reasons	# Removed	% of Removed
Electrodes removed	418	100
Broken electrodes	82	20
Nonfunctional electrodes	61	15
Adverse sensation	12	3
Redundant electrodes	10	2
Electrode site changed	46	11
Patient left program	148	35
Granuloma formed	5	1
Suspected infection	3	1
Other reasons	7	2
Reason unidentified	45	11

Using life table analysis methods (BMDP Statistical Software, Los Angeles, Calif.), the probability of electrode survival was determined. As can be seen in Fig. 1, the electrode survival probability is 90% for 6 months, 82% for 1 year, 63% for 3 years. No statistically significant differences in electrode survival rates were found when comparisons were made under the following conditions: electrodes implanted at the dorsal or volar connector sites; electrodes from different wire manufacturers; electrodes implanted in different muscle groups; electrodes that crossed the wrist joint in subjects with and without voluntary wrist control; electrodes implanted from 1978-1983 and those implanted from 1984-1988.

Analyzing the stability of stimulus thresholds over time indicates that while for certain electrodes there is some variability in the threshold pulse-width, 65% of the electrodes have a standard deviation of less than 10 usec.

DISCUSSION

The implementation of an electrode data tracking system has allowed for a detailed analysis of electrode reliability. Complications from the implantation of intramuscular electrodes have been infrequent (Table 1), which subsequently were alleviated by removal of the electrode. A survival probability of 90% for a six month period is encouraging, since it is expected that subjects will return to the laboratory twice a year for system maintenance and upgrades. The lack of differences in survival probabilities for electrodes that were implanted in different sites or at different times indicate that the failure rates are due to the inherent limitations in size and complexity of a percutaneous electrode. Information from this study has been incorporated into the design of permanently implanted electrodes for implantable stimulator systems, so that these systems should have a greatly reduced rate of electrode failure.

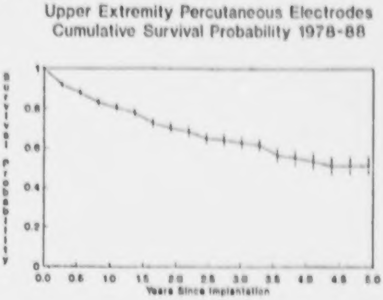

Fig. 1. Electrode Survival Probability

CONCLUSIONS

The percutaneous intramuscular electrode technique has been shown to be a safe and effective method to electrically excite paralyzed muscle. Only minor complications have occurred in a few electrodes. The probability of electrode survival is sufficient for the present clinical system.

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EFFECTS OF FNS ON QUADRICEPS MUSCLE STRENGTH, BULK AND FATIGUE IN SIX SPINAL CORD INJURED SUBJECTS

P3.26

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INTRODUCTION

Due to the functional degeneration that succeeds spinal cord injury (SCI), wheelchair-bound patients may experience problems such as increased abdominal pressure, renal dysfunction, pressure sores, muscle atrophy and osteoporosis. Thus, it is physiologically beneficial for those with SCI to stand for short periods of time. This can be achieved with FNS. It was essential for subjects to first undergo muscle restrengthening before standing under FNS control could be attempted. A pilot study was undertaken to provide experience of FNS and its effects on quadriceps muscle and to develop a muscle training programme suited to our particular needs. This study formed the initial stage of the University of Cape Town FNS programme entitled Project REWALK.

METHODS

The six healthy SCI subjects (three males and three females) consisted of two tetraplegics (C5,6; C7) and four paraplegics (T4 -T9). The mean (± 1SD) age at injury and present age were 17 (± 4,3) and 28 (± 10) years respectively. Subjects regularly performed FNS quadriceps exercise at home using a portable two-channel muscle stimulator (Figure 1). Stimulation was applied via carbon-rubber electrodes (5x10cm) used with electrolyte gel. The stimulus was a symmetric biphasic pulse train (10 sec "on" and 10 sec "off" time, ramping from zero to maximal current over the first 5 seconds) of 80 mA, 25 Hz and 200 us. Weights were designed to strap around the subject's ankles to provide a load to exercise against to optimise the training effect.

Subsequent improvements in muscle strength and fatigue were assessed at three-weekly intervals. The strength test lasted 20 seconds and utilised parameters of 80 mA, 25 Hz and an increasing pulsewidth to a maximum of 999 us. A straingauge measured the force resulting from the knee extension. The parameters for the fatigue test (3 minutes) were 80 mA, 25 Hz and 600 us. A potentiometer was used to measure the angular droop in knee extension during a sustained contraction with a 2 kg weight applied to the ankle. Changes in muscle bulk were monitored by bi-annual Magnetic Resonance Imaging (MRI) scans of the cross-section of the mid-thigh. The scans were digitised to determine changes in the relative percentage area of the total cross-sectional area of the following compartments: anterior (quadriceps), posterior and medial, bone, marrow and subcutaneous fat.

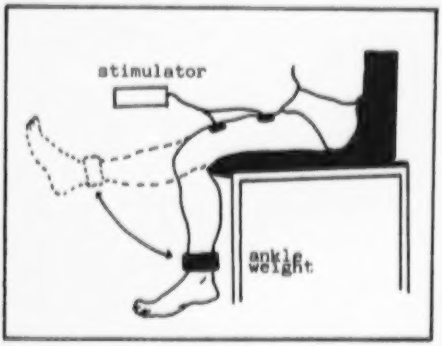

Figure 1: FNS quadriceps exercise

RESULTS

The results were analysed as six individual case studies and general trends were observed. The two tetraplegics responded differently from the paraplegics. The means (± 1SD) increases in strength for the four paraplegics were 97,8% ± 59,6 and 171,2% ± 118,1 for the left and right legs respectively. A %TD(ht) index, namely the percentage of the total droop that had occurred by the half-test (90 seconds) mark, was used to assess improvements in muscle fatigue. The left legs showed a 16,7% improvement, while the right legs improved only 3,9%. The variabiflity between the subjects was too wide to attach significance to these results. Data for the changes in muscle bulk are only available for three subjects. The MRI scans indicated, firstly an increase in the percentage area of the quadriceps muscle ($0,05<p<0,1$) namely 4,43% ± 3,4 and 2,7% ± 2,1. Secondly, a decrease in the percentage area of the subcutaneous fat compartment ($p<0,05$) namely 4,73% ± 1,4 and 3,43% ± 1,1 for the left and right legs resepctively.

DISCUSSION

Certain factors need to be taken into account when assessing the results of this pilot study. These include the nature of our six subjects, namely - employed, busy and with limited time to devote to FNS during the workday. Thus, the 'home use' format of the programme was very convenient for this subject group and to the personnel monitoring the programme. Disadvantages of this format were the absence of fixed group sessions of FNS and thus the need to rely on the subjects to maintain accurate records of their FNS exercise data at home for future analysis. The subject group was of a heterogenous nature and thus not suited for tight statistical study.

Subjects varied in their responses to FNS in strength and fatigue according to their individual circumstances. Subjects whose initial strength response was strong responded well to the FNS exercise. The strength test was limited by a 100 N safety cut-off point (as measured by the straingauge) in the strength test stimulation programme. Four subjects reached this cut-off point. Due to various personal circumstances, three subjects discontinued FNS for two to six months. One subject has surprisingly maintained his previous quadriceps strength after the six months, while the other two showed a decrease in muscle strength after this time. A pattern emerged in that an improvement in muscle strength was generally accompanied by an improvement in muscle fatigue resistance. MRI scans indicated that the quadriceps muscle bulk had increased and the quantity of subcutaneous fat had decreased in response to the FNS exercise.

CONCLUSIONS

This pilot study provided experience in the field of FNS which will be used to modify and improve the programme in future. FNS exercise resulted in:

- a significant increase in quadriceps muscle strength of 97,8% ± 59,6 and 171% ± 118,1
- an improvement in muscle fatigue of 16,7% ± 25,8 ($0,05<p<0,01$ left leg)
- an increase in quadriceps muscle bulk of 4,43% ± 3,4 and 2,7% ± 2,1 ($0,05<p<0,1$)
- and a significant decrease in subcutaneous fat of 4,73% ± 1,4 and 3,43% ± 1,1 for the left and right leg respectively.

There was however a wide variability in these improvements between the individuals in the test group. This we ascribed to the heterogenuity of the group.

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MUSCULAR EFFECTS OF TWO FNS EXERCISE MODES FOR THE SPINAL CORD INJURED

P3.27

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ABSTRACT

This study examined the effects of using two functional neuromuscular stimulation (FNS) exercise modes for spinal cord injured (SCI) subjects. Instrumentation consisted of a specially constructed chair and computerized stimulation system for inducing FNS knee extension (weight-lifting) exercise with the paralyzed quadriceps muscles, and a commercially available cycle ergometer that is driven by FNS of several paralyzed lower-extremity muscles. Seven SCI subjects (4 quadriplegics and 3 paraplegics) participated in 7 weeks (3 sessions per week) of progressive intensity FNS knee extension training followed by 7 weeks of FNS cycle ergometer training. The results showed statistically significant increase in thigh girth and quadriceps strength after knee extension training. A statistically significant increase in power output level occurred after cycle ergometer training. Thigh girth increases resulting from the knee extension training were maintained by the cycle ergometer training. It was concluded that the instrumentation and training protocols used were effective in increasing muscle strength, endurance, power output, and thigh girth, without any observable adverse effects.

INTRODUCTION

FNS has been used with SCI subjects to provide dynamic knee extension exercise by inducing contractions of the paralyzed quadriceps muscles (1). Recent studies on humans demonstrated that the use of such dynamic exercise (movement through a range of motion) and well established weight training protocols (e.g., progressive resistance) provided significant increase in muscular strength and endurance (1,2). FNS has also been used to enable paraplegics and quadriplegics to perform leg cycle ergometry (2,3). This type of exercise may be more effective for improvement of muscular and cardiopulmonary endurance rather than strength. The purpose of this study was to evaluate the effects of these two FNS exercise modes (knee extension weight lifting and cycle ergometry) for increasing the strength, endurance, power output, and girth of the FNS-active paralyzed muscles in the lower limbs.

METHODS

Subjects. Seven neurologically complete SCI males (mean age = 26 yr, wt = 75 kg) participated in this study. Level of injury ranged from C5 to T3. The average time since injury ranged from 4-8 years. After signing the appropriate consent form and completing a physical examination, subjects began their FNS knee extension training.

FNS Knee Extension Exercise. Instrumentation used for FNS knee extension weight lifting was previously described (2). This device utilized limb-position feedback with a microprocessor for precise control of stimulator output and muscle contractions. Stimulator output ranged from 0-150 VDC, with a maximum current of 150 mA. Pulse frequency was 35 Hz, and rectangular wave pulse width was 0.3 msec. Surface electrodes were placed over motor points of the quadriceps muscles. Ramped stimulation output provided smooth, controlled movements at a rate of about five lifts per minute. All subjects received 7 consecutive weeks (3x/wk, 15min each) of progressive resistance, knee extension exercise on this device. The initial load was 1.5 kg, and was increased progressively with improved performance until the subject attained a maximum of 7.0 kg. Subjects were required to complete 15 minutes of exercise at a given resistance before the load was increment by 0.5 kg at the following session.

FNS Cycle Ergometer Exercise. After completing the 7 weeks of knee extension training, all subjects received 7 continuous weeks (3x/wk, 15 min each) of exercise on the FNS cycle ergometer (ERGYS 1; (Therapeutic Technologies Inc., Ft. Lauderdale, FL). This device uses computer-controlled FNS of the quadriceps, hamstring, and gluteal muscle groups to pedal at the target cadence of 50 rpm . All subjects began with a power output (PO) of 0 watts (unloaded flywheel) for the first three sessions which was intended to habituate them to this mode of exercise. During the training program, PO was increased by 6.12 W (0.125 kp load) increments after 15 minutes of uninterrupted cycling could be performed at a given load. Blood pressure and heart rate were monitored during all exercise training for safety reasons.

Muscle Performance Variables. Leg girths (mean values for both legs) were defined as circumferences along leg at 10 and 20 cm above the proximal edge of the patella (distal and mid-thigh measurements) and 10 cm below the distal edge of the patella (calf measurements). Measurements were obtained at rest before and after 7 weeks of the knee extension training program and after 7 weeks of the cycle ergometer training program. The measurements after training were taken at least 24 hours following the last respective training session to avoid any acute effects of exercise. Knee extension "muscle performance" (kg·reps) was defined as the mean (during an exercise session for both right and left legs) of the products of the resistive load (kg) and the maximal number of repetitions (reps) performed. For FNS cycle ergometry, PO values were calculated as the product of pedalling cadence (rpm), load (kp), and 0.98 (a proportionality constant, 6.00 m / 6.12 kpm/W).

Statistical Analysis. Data for each dependent variable were analyzed using separate 1-way repeated measures analyses of variance (ANOVAs) across measurement intervals. Significant main effects were investigated by Tukey pairwise multiple comparison tests. The 5% level of significance was used with all statistical hypothesis testing.

RESULTS

Following the 7 weeks of FNS knee extension training, significant increases in thigh girth measurements were found. However, the calf girth measurement did not increase. After the 7 weeks of FNS cycle ergometer training, there were no further changes in any girth measurements, and the thigh girth increases found after knee extension training were maintained. Quadriceps muscle strength improved significantly during the FNS knee extension exercise training. Figure 1 shows the progressive increase in mean resistive loads (from 1.5 to 6.0 kg) applied at the ankles during FNS knee extension exercise. Endurance also increased during this training, and as a result, overall muscle performance increased from 74 to 451 kg.reps (Figure 1). Since improvements were similar for both legs, mean values for both legs are given in Figure 1. Power output capability during the 15-min exercise bouts significantly increased during the 7 weeks of FNS cycle ergometer training (Figure 2). Mean PO ranged from 0 W at the start of the exercise training program to 15 W at the completion of the program.

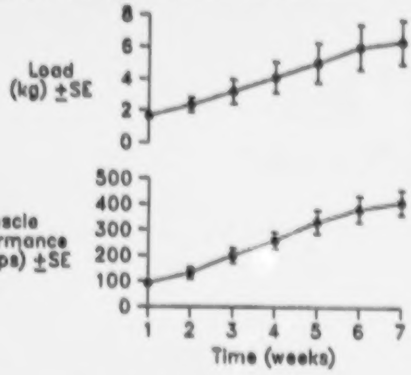

Figure 1 Mean resistive load and muscle performance progression during seven weeks of knee extension training

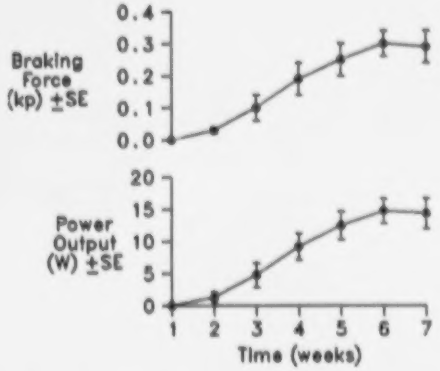

Figure 2 Mean power output and flywheel braking force (kp) during seven weeks of cycle ergometer training

DISCUSSION

The active contractions of the quadriceps muscles that occurred during FNS-induced knee extension training resulted in a significant increase in thigh girth, which was maintained during FNS cycle ergometer training. However, the passive movement of calf muscles (no FNS) had no effect on their girth. Thus, active FNS-induced contractions of the loaded musculature appear to be required for hypertrophy to take place. Although FNS cycle ergometer training can apparently maintain the increased thigh girth obtained during FNS knee extension training, it is not currently known if FNS cycle ergometer exercise can by itself evoke the same magnitude of girth increase. The increase in leg girths and quadriceps strength/endurance after knee extension exercise training may have been due to histochemical adaptation within these muscles (4,5).

In contrast to the weight-lifting (strength) training, cycle ergometry may be better suited for the development of muscular endurance, as well as promoting higher levels of cardiopulmonary fitness (3). Typically, initial FNS cycling sessions used a PO of 0 W and most subjects experienced fatigue within a few minutes. However, following 7 weeks of training, most subjects were able to complete 15 minutes of this exercise at a mean PO of 15 W. The significant increase in PO capability and endurance during 7 weeks of cycle ergometer training of the SCI subjects may in part be due to local histochemical changes within the active muscles. However, it may also be due to enhanced delivery of blood, oxygen and metabolic substrates to the active muscles, and facilitated removal of metabolic end-products (6). More research is needed to document the potential peripheral and central training effects that enhance muscle performance for FNS exercise.

In conclusion, the two FNS exercise modes used in this study were effective in increasing thigh girth, muscular strength and endurance. There were no observable adverse effects, and the progressive intensity exercise permitted FNS exercise for all subjects to improve their performance. FNS exercise needs to be part of one's lifestyle if beneficial effects are to be maintained.

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P3.28

ASSESSMENT OF MOTOR AND SENSORY PATHWAYS: ENHANCEMENT OF SELECTION CRITERIA FOR FUNCTIONAL ELECTRICAL STIMULATION

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ABSTRACT

The purpose of this poster is to propose a scheme to augment the selection of patients for functional electrical stimulation (FES). Magnetically induced central motor evoked potentials (CMEPs) and somatosensory evoked potentials (SSEPs) permit noninvasive assessment of pathways between the brain and the muscles to be stimulated. Animal studies and preliminary results in human subjects indicate that these studies can predict motor recovery after spinal injury. Pilot study also indicates that magnetic stimulation (MS) is useful to evaluate the lower motor neuron. These findings have immediate clinical application to the selection of candidates for early FES to augment motor recovery and to the identification of patients who could benefit from implanted FES devices for daily function.

INTRODUCTION

Selection of candidates for FES necessitates accurate information on both the innervation status of muscles targeted for FES and the potential for enhancement of volitional control of paretic or paralyzed muscles. Traditional electrodiagnostic procedures have not provided adequate information. During the months immediately following stroke, head trauma or spinal injury, electromyography may give a false indication of anatomical denervation. The presence of fibrillation potentials appears to be related to a change in suprasegmental input (1). Although SSEPs have been used to assess the integrity of sensory pathways between the periphery and the sensory cortex, this test cannot predict either the status of central or peripheral motor pathways nor the potential for motor recovery.

Technology now exists to evaluate the motor pathways from the cerebral cortex to the muscles paralyzed by spinal injury and to delineate the extent of associated lower motor neuron damage (2,3). MS can be employed to comfortably evoke motor potentials. In controlled animal studies, the return of movement after SI correlated closely with the return and normalization of the amplitude of the CMEP (4). In spinal injured cats, the CMEP was a significant correlate of ambulation recovery (4). Spinal injured patients with no sensation distal to the level of spinal injury, absent SSEPs but intact CMEPs have demonstrated progressive return of volitional motor control during an 18 month period after their initial injury (4).

Preliminary clinical reports have indicated the comfort, safety and efficacy of MS in eliciting peripheral motor potentials (5). The reported variability in latency and amplitude of the evoked motor potentials, however, is greater than that observed in electrically stimulated potentials. Various investigators have reported, as well, that evoked potentials cannot be produced by MS over the scalp in some subjects.

The purpose of this paper is to propose an evaluation of potential candidates for FES and to report preliminary data on CEMPs in the upper and lower limbs.

METHODS

In a pilot group of normal indivuduals, both SSEPs and CMEPs were performed. The median nerve was stimulated at the wrist and sensory potentials recorded at the elbow, above the clavicle, over C2 and over the cerebral cortex (C3 or C4). In the lower limb the tibial nerve was stimulated at the ankle and potentials recorded at the knee, over L4 and C2 and at the scalp (Cz'). Motor potentials were evoked by stimulation over the scalp, C2, above the clavicle, over the ulnar nerve at the elbow and the wrist with recording electrodes over the abductor digiti minimi. In the lower limb, motor potentials were recorded over the abductor hallucis in response to stimulation over the scalp, C2, L4 and at the popliteal fossa.

Motor potentials also were elicited in key functional muscles of various myotomes by MS over the scalp and the vertebral column (C2 or L4). Either compound muscle action potentials (surface recording electrodes) or motor unit action potentials (monopolar needle electrodes) were recorded simultaneously in the abductor pollicis brevis, extensor carpi radialis longus, biceps and triceps. The same procedure was repeated for the tibialis anterior, soleus (or plantar flexors), vastus medialis and tensor fascia lata. Facilitatory maneuvers, including contralateral muscle contraction, resisted head and trunk rotation and modified Valsalva maneuvers, were evaluated.

A four channel, disk-operated electrophysiological system (Cadwell Quantum 84, MES-10, Cadwell Laboratories, Kennewick WA 99336) was used for sensory and motor measurements. A Yellow Springs telethermometer (YSI, Inc., Yellow Springs OH 45387) recorded skin temperature.

RESULTS

Peak SSEP latencies were commensurate with previously reported values for both the upper and lower limbs. Sensory conduction velocities ranged from 54 m/sec in the lower limb to 61 m/sec in the upper limb. Latencies and conduction velocities for magnetically evoked motor potentials were similar to those reported for conventional electrical stimulation of peripheral nerves. The amplitudes were equivalent to those reported for electrical stimulation with the exception of smaller potentials at the wrist and ankle (8.9 and 4.8 mV respectively). Central motor latencies (scalp to C2) averaged 8.7 msec in the resting state and 6.7 msec after facilitation. Although no single method of facilitation appeared to be more effective than the others, all increased the amplitude of the motor potentials by a factor of 2.5 to 3.0 and the latency was reduced by 18% (.15- 42.8%). Motor potentials were evoked in all target muscles by MS over the scalp. Motor potentials could not be consistently elicited in the lower limb when MS was applied over C2. Although amplitudes varied, the repeatability of the evoked latencies is much better than what has been previously reported (r=.95 - .75 on test-retest).

CONCLUSIONS

These preliminary results indicate that magnetically evoked motor potentials can be used to augment the assessment of both peripheral and central pathways. Although the amplitude of the CMEPs was more variable with scalp than peripheral nerve stimulation, the presence of evoked potentials in muscles targeted for FES would indicate the potential for improved voluntary control of those muscles. Contrary to prior reports, potentials were evoked in response to scalp stimulation in all lower limb muscles tested. Facilitation techniques increased amplitudes and reduced latencies. The facilitation techniques employed did not involve contraction of the muscle under examination and thus the need to distinguish voluntary motor unit activity from the evoked motor potential was avoided. Discomfort was not a problem and deep structures such as the spinal cord and the brachial plexus were easily depolarized. This would be advantageous in spinal injury where potentials may be of reduced amplitude.

Stimulation over the cervical spine (C2) did not result in activation of lower limb muscles in most subjects. It appears that the motor tracts to the lower limb are inaccessible in this region of the cord. A new magnetic coil design is under evaluation to determine if these pathways can be accessed with a more highly focused magnetic field.

The findings of these motor and sensory assessments appear to correlate with residual motor control in the chronic spinal injury patients studied to date. Additional data will be gathered on normal as well as acute and chronic spinal cord injured individuals as part of a grant funded by NIDRR (#H133G80142).

The results of this study will have clinical application to the selection of newly injured patients for short term FES to improve motor recovery and to the identification of patients who can benefit from implanted stimulation devices to improve daily function.

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P3.29

FEEDBACK CONTROL OF THE KNEE DURING THE STANCE PHASE OF PARAPLEGIC FES GAIT, USING A STIFFNESS REGULATOR

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ABSTRACT

This paper describes the application of a feedback controller for the regulation of knee motion during the stance phase of FNS gait in paraplegic subjects. The controller, a quick response Pulse Width/Stimulus Pulse frequency controller, is needed because of the short duration of the stance phase. The single input to the controller is an algebraic combination of insole knee force information and goniometer knee angle information which approximates knee stiffness and is known as the "stiffness configuration." The paraplegic muscles are stimulated via percutaneous electrodes and the subjects gain additional support from a rolling walker. This paper reports preliminary work and basic design of the knee angle regulating stiffness configuration.

INTRODUCTION

Unimpaired human gait is characterized by certain general angle trajectories. While individual variations are great enough to allow identification of a person by their gait, certain characteristics prevail from subject to subject. In gait obtained via functional electrical stimulation of paraplegics, specific deviations from the "normal" knee trajectories have been observed. These differences are common to the FES patients, and appear to reflect deficiencies of our FES walking system.

The unimpaired knee trajectory is a smooth double-humped curve. The first rise indicates knee flexion during the stance phase of the leg and the second rise indicates flexion during footswing as in Fig. 1. In FES paraplegic walking, the knee trajectory lacks the first occurrence of flexion and the second is markedly delayed [1], [2]. This lack of flexion during the stance phase not only contributes to the unusual appearance of FES gait, but also may lead to excessive occurrence of hyperextension. In addition, the energy consumption of FES paraplegic walking is many times that of unimpaired walking. According to Inman [3], the knee angle trace of the unimpaired individuals (shown in Fig. 1), prevents these problems of FES walking in at least two different ways: 1) knee flexion smooths the abrupt changes of the center of mass at the beginning and end of stance phase, and 2) knee flexion reduces energy consumption by minimizing vertical displacement of the center of mass during early stance phase. In other words, the unimpaired knee trajectory reduces energy consumption by limiting the vertical path of the center of mass. In addition, hyperextension during stance phase in normal walking is not a problem.

Regulation of the knee angle trajectory in paraplegic walking to more closely follow the unimpaired pattern may be achieved by closed loop control of stimulation using feedback of knee angle and vertical force information. We are investigating if this will improve the present FES walking system in terms of reduced knee hyperextension, reduced energy requirements, greater speed, longer duration, improved cosmesis, and reduced hand and arm support.

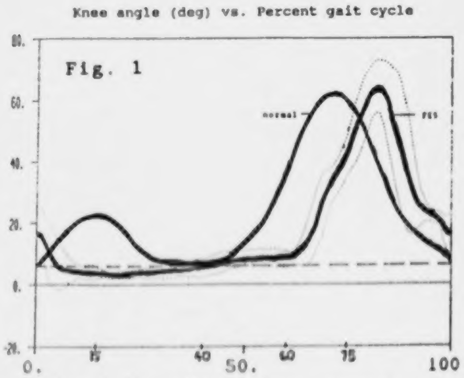
Knee angle (deg) vs. Percent gait cycle

Fig. 1

PRE-PROGRAMMED WALKING

The present system uses pre-programmed stimulation parameter sequences for various muscles, which are triggered for each phase of gait (as detected by footswitches, patient handswitch commands or approximated timers) [4]. This stimulation pattern is developed by trial and error for each subject. The stimulation parameters incorporate a safety factor, so that muscle fatigue and disturbances will not cause the subject to fall. As a result, the overall system is not as efficient as desired. Using this system, subjects have walked a distance of 330 meters and achieved a maximum velocity of .8 meters per second [5]. Reducing stimulation to the knee extensors immediately after heelstrike will prevent hyperextension. However, we cannot safely reduce the stimulation without feedback because, as the recently landed leg begins weight acceptance, the knee will tend to flex if stimulation is insufficient. The slightly different timing of weight acceptance in each subsequent step prohibits accurate regulation of the knee extensors based strictly on pre-planned, timed sequences. In addition, the effects of fatigue render it impossible to accurately predict muscle responses in advance. The extra stimulation of knee extensors that is needed to insure support, thus, often results in hyperextension and excessive vertical motion of the center of mass, hence increased energy consumption.

THE STIFFNESS CONFIGURATION

At heelstrike, angle control is needed

to obtain appropriate knee flexion without hyperextension. As weight is accepted, the increasing force on the leg requires increased stimulation. Before toe-off, the knee should again be flexed slightly. However, the limited duration of one cycle of the stance phase (500-600 millisec.) prohibits switching between different controllers. Our approach to knee control in this situation is to use the " stiffness controller configuration" [6]. This controller combines force (from insoles) and position (from goniometers) information into a single feedback loop, so as to regulate joint stiffness. Although knee extension moment is the force of interest, we can obtain or approximate this value from the insole sensors, which correspond to ground reaction force (since knee and ankle angles are measured at each instant).

The rapid response needed by the feedback controller suggests that the PW/SP controller [7] may be most appropriate. It and a pulse width modulated controller are being compared and evaluated.

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Functional Neuromuscular Stimulation for Stance and Ambulation: Six Month Evaluation of Psychological Effects

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Abstract

Persons with spinal cord injuries (SCI) who were participating in Functional Neuromuscular Stimulation (FNS) research to achieve stance completed two psychological assessments six months apart to assess the effects of FNS on psychological well-being. Case reports for five persons, three of whom completed psychological assessments before beginning FNS participation, are reported. FNS did not appear to cause negative effects, per se, though persons who reported that they were participating primarily to restore function appeared to have lower levels of well-being. FNS participation may have allowed well-functioning persons to enhance their sense of well-being. Assessment of new, and monitoring of continuing FNS participants, is planned.

Introduction

Technological developments that allow standing or walking for persons with SCI, such as Functional Neuromuscular Stimulation (FNS), may change rehabilitation practices. FNS generally involves placing surface electrodes over muscle groups to achieve useful contraction. The objective of this study was to describe the psychological consequences of participating in FNS research when outcomes are uncertain but when participants often see walking as being critical to their well-being. The ability to cope with life disruptions, to appraise FNS benefits realistically, and to deal with uncertain outcomes may be essential to appropriate use of FNS.

Methods

FNS procedures described by Cybulski, Penn, and Jaeger (1985) were used as part of an ongoing study which sought to investigate means of achieving stance in persons with SCI. Data are reported from five persons for whom six month follow-up data were available. Two of the participants received a neuromuscular stimulator before and three received a stimulator after the first evaluation.

The first interview provided information about the project and emphasized the goals as being research-oriented rather than treatment-oriented, and evaluated participant's ability to cope with the physical and psychological demands of the research. A life history was obtained and mental status was evaluated. Signs of depression, thought process disorders, substance abuse, anger control difficulties, and authority conflict were sought.

Subsequent interviews assessed characteristic coping strategies, rehabilitation experiences, and anticipated outcomes of FNS research. Psychological tests were administered at the first evaluation and at a six month follow-up. These tests included Linkowski's (1971) Acceptance of Disability Scale (ADS), Beck's (1967) Depression Inventory (BDI), the Tennessee Self-Concept Scale (TSCS; Fitts, 1965), and a Q-sort questionnaire developed by Heinemann and Shontz (1984) that assesses theoretical stages of reaction to crises. Items are sorted into a quasi-normal distribution to describe typical and ideal selves. Congruence between these sortings was assessed by simple correlations. The Representative Case Method (Shontz, 1965; Spotts and Shontz, 1980) was adapted for this investigation which requires the intensive study of carefully selected persons, each of whom is examined in-depth over an extended period of time and considered as expert consultants given that they are in a unique position to report on the effects of and reactions to the rehabilitative process under investigation.

Results

Case 1 is a divorced, black man with 12 children who incurred an incomplete injury at the T5 level from a gun shot wound during a struggle for the gun with his ex-wife. Case 2 is a married, white man who incurred a thoracic injury when he lost control of his motorcycle while accelerating onto an expressway. Case 3 is a single, Greek emigrant woman who incurred an injury at the C-7,8 level during an automobile accident. Case 4 is a remarried, naturalized South American native man who incurred a T8 injury in a jeep accident. Case 5 is divorced, black man who was injured at the T3 level when being shot by an unknown assailant in a parking lot late one evening.

Table 1
Psychological Test Data for Five Cases

				AD		BDI		TSCS**				Q-Sort	
				%iles		Raw Scores		Total		Physical		*r* values	
Case #	Age	Sex	Years after SCI	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
1*	35	M	3	33	30	1	8	49	41	48	38	.39	.37
2	31	M	9	79	79	0	0	52	69	49	45	.55	.82
3	31	F	2	71	52	4	5	54	--	44	--	.59	.70
4*	32	M	5	29	16	7	5	43	43	38	48	.44	.37
5	42	M	7	59	77	3	2	67	67	52	61	.68	.70

* Subjects who received stimulator prior to initial evaluation.
** TSCS *T*-scores are reported for both the total score and physical subscale. TSCS post-scores were missing for one subject.

Table 1 shows that normal range values were obtained for all participants on all normative measures with the exception of Case 1 who obtained a low physical scale TSCS score at the second evaluation and Case 4 who obtained a low physical self TSCS score at the first evaluation and a low AD score at the second evaluation. Follow-up scores generally were consistent with first evaluation scores with the exception of Case 2 who increased on the TSCS total score. Case 1 showed a moderate decrease on the TSCS physical scale while Case 4 obtained an equivalent increase. Case 3 showed a moderate decrease on the AD between the first and second evaluation while Case 5 showed a moderate increase. Q-sort correlations were consistent between assessments except Cases 2 and 3 who had larger correlations at the follow-up evaluation. The two cases who received the stimulator before the first evaluation had lower scores on most measures and changes on these measures were more likely to be in the direction of less adjustment compared to the other subjects.

Discussion

None of the participants appeared to be adversely affected by FNS participation. However, the three participants who received the stimulator after the first evaluation appeared to have greater levels of well-being than did the cases who received a stimulator before the first evaluation. Participation by these two subjects appears to have been motivated by a strong desire to walk.

In conclusion, participants who received the stimulator before the first evaluation did not appear to experience negative effects, participants who were involved in FNS for restorative reasons may have been more reactive to life disruptions, and the measures provided a consistent view of psychological functioning between the 2 evaluations. Additionally, each participants' adjustment appeared to be unique, suggesting the value of a case-study approach to understanding adjustment with FNS. Continued monitoring of participants and screening of new participants is planned to better understand the long-term consequences of participating in research where highly valued outcomes are uncertain.

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TIBIAL TRABECULAR BONE DENSITY VS TIME SINCE SPINAL CORD INJURY

P3.31

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ABSTRACT

Trabecular bone density (TBD) was determined at the distal end of the tibia in 14 spinal cord injured (SCI) subjects in order to estimate the time course of disuse osteoporosis. Scans of 1.5 mm thickness were performed using a specialized quantitative computed tomography (QCT) technique which incorporated custom designed and constructed instrumentation. Results showed a significant inverse curvilinear relationship between time since injury (TSI) and TBD, with an apparent high rate of bone loss in the first two years (0.15 g/cm^3 per year) and an apparent slowed rate of bone loss after 2 years (0.01 g/cm^3 per year). TBD was not related to age, level of injury (quadriplegics vs paraplegics), completeness of injury, body surface area (height, weight), or calf girth in this group of SCI subjects. This cross sectional study indicates that therapeutic techniques to intervene in the progression of disuse osteoporosis may be most effective immediately post SCI, and that measurement techniques must be sensitive enough to detect slight changes in bone density.

INTRODUCTION

Disuse osteoporosis is a major problem for SCI individuals. Serious medical problems such as renal calculi, heterotopic ossification, and frequent lower extremity fractures have been documented in the literature [1,2]. Loss of protein and calcium salts occurs most rapidly in the first few weeks after injury. This loss of calcium from the bone and its excretion in the urine is responsible for the development of bladder and renal calculi in SCI patients [1]. Excessive calcium mobilization from bones predisposes the SCI patient to ossifications in the paralyzed portions of the body. When calcium is deposited in muscle (myositis ossificans) or near joints (periarticular ossifications), joint motion can be severely restricted or even stopped completely with the fusion of a joint (ankylosis) [2]. Pathological fractures resulting from minor trauma often occur in the lower extremities of SCI patients secondary to osteoporosis. Each of these complications related to disuse osteoporosis can create insurmountable barriers to rehabilitation for the SCI patient.

Studies of bone loss have included long-term bed-rest and zero gravity to simulate conditions of disuse for healthy subjects [3,4]. Donaldson and co-workers used gamma-ray transmission scanning to document calcaneal bone loss in healthy adults who were on bed-rest for 30 to 36 weeks [3]. They found 25% to 45% bone mineral loss within these periods of bed-rest. Studies of astronauts in weightlessness have shown bone density losses of 1% to 2% per month [4].

Studies of bone loss in SCI subjects have been very limited. Lew used standard CT scans of the femur to measure cortical bone density in SCI and control subjects [5]. He found cortical bone density to be 9.5% less in paraplegics compared to normals. Hangartner has described a QCT method to improve precision and allow measurement of trabecular bone density (TBD) in the peripheral skeleton [6]. Using the QCT technique in a pilot study, TBD of paraplegics (n=3) was shown to be 58 to 75% less than that of matched non-paralyzed control subjects (n=3) [7]. Although this study has provided some indication of disuse osteoporosis in SCI subjects, it has not shown the relationship of bone loss to duration of time since SCI. The purpose of the present study is to determine TBD at the tibia in a cross-sectional sample of SCI subjects and to compare it with selected anthropometric parameters.

METHOD

The sample included 14 SCI subjects (7 paraplegic and 7 quadriplegic). Medical screening data and informed consent were obtained for all subjects. Anthropometric measurements included height and weight (from which body surface was calculated) and calf girth.

Subjects were scanned in a seated position with the right leg stabilized in the QCT scanner using specially made splints. Scans of 1.5 mm thickness were performed at 2 mm intervals on the right distal tibia of each subject using QCT.

All TBD measurements were performed using a specially constructed (in the Biomedical Imaging Laboratory at Miami Valley Hospital, Dayton, OH) CT scanner. This scanner is a translate/rotate type and uses a ^{125}I radio-isotope as source [6]. The individual images are analyzed with a semi-automatic procedure which leads to a precise definition of the inner trabecular area of the bone. The density values are averaged over this area, and the area-weighted mean over six to eight sections represents the volume average of TBD for the distal tibia.

RESULTS AND DISCUSSION

Anthropometric characteristics of the subjects were not significantly different between the quadriplegic and paraplegic groups. Age ranged from 22 to 40 yrs ($\bar{x}$=30.6 yrs), weight 61 to 91 kg ($\bar{x}$=73.2 kg), height 167 to 190 cm ($\bar{x}$=180.5 cm), and body surface area (BSA) 1.7 to 2.1 m^2 ($\bar{x}$=1.9 m^2). TSI for subjects ranged from 0.4 to 15.0 years ($\bar{x}$=7.0 yrs). Thirteen males and one female participated.

TBD for all subjects ranged from 0.09 to 0.55 g/cm^3 ($\bar{x}$=0.25 ± 0.14 g/cm^3). No significant difference in TBD was found between quadriplegics ($\bar{x}$=0.27 ± 0.14 g/cm^3) and paraplegics ($\bar{x}$=0.23 ± 0.15 g/cm^3). TBD and TSI were found to have a significant negative relationship ($r=-0.66$, $p < .01$). A nonlinear regression analysis (shown in fig. 1) provided the best fit for TBD and TSI: $TBD = 0.356 \times TSI^{-0.306}$. The curvilinear relationship showed an apparent higher rate of bone loss in the first two years of injury (0.27 g/cm^3 per year) and an apparent slower rate of loss in later years (0.01 g/cm^3 per year). The rate in later years is only slightly higher than that in normals after the age of 40 years except during the accelerated bone loss in females after menopause.

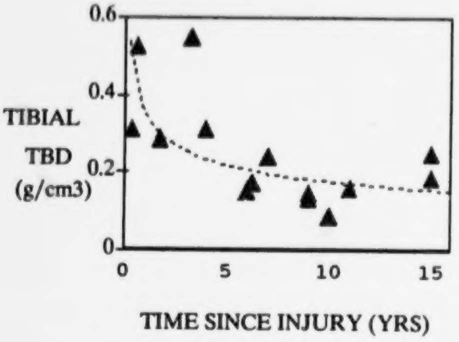

Figure 1. Scattergraph showing relationship between years since injury and TBD for the cross section of SCI subjects (n=14).

Although the data presented are cross sectional, the apparent rate of bone loss found corresponds to disuse studies in healthy subjects [4]. The absence of muscle contraction and weightbearing would be expected to accelerate bone loss in recently injured SCI subject. This loss will eventually stop as a new steady state for Ca^{++} metabolism will occur at lower bone density.

No relationship was found between TBD and level of injury, body surface area (height and weight), calf girth or age. The lack of relationship between other parameters and TBD reflects the independence of bone loss from anthropometric parameters in the SCI individual which have been shown to be related in normal subjects. Longitudinal study of the relationships would help to clarify the influence of anthropometric parameters.

CONCLUSIONS

This cross sectional study indicates that time since injury has a curvilinear inverse relationship to TBD. The implication is that a therapeutic intervention, either for prevention of bone loss or to decrease the rate of bone loss in disuse osteoporosis, will be most effective if administered as soon as possible following SCI. In addition, the changes seen in bone density are small enough that special instrumentation is required for accurate tracking of bone loss. QCT measurements of the tibia are being continued to determine the influence of continued disuse as well as the effect of various exercise modes utilizing functional electrical stimulation of the lower limbs.

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QUANTITATIVE ANALYSIS OF DYSPHAGIA : DEVELOPMENT OF A TONGUE FORCE MEASUREMENT SYSTEM

P3.32

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ABSTRACT

In order to quantitatively analyze tongue strength, a tongue force measurement system has been developed for measuring upward and lateral tongue thrusts. The force transducer employed consists of a cantilever beam instrumented with strain gauges and interfaced to a microcomputer. The system is capable of high-speed data acquisition, data processing, and audio/visual feedback, and it accomodates all test subjects, providing comfort and standardization of test data. 15 normal subjects and 5 dysphagic patients have been tested to date, and their results have verified the reliability of the system. Applications of this system are foreseen specifically in the diagnosis and treatment of oral phase swallowing disorders.

INTRODUCTION

The tongue plays a critical role during the oral phase of swallowing. A lack of tongue strength or coordination could, in effect, lead to swallowing disorders. Therefore, tongue strength may be an appropriate, quantitative parameter in the analysis of the oral phase of swallowing.

The current methods of diagnosis and therapy for dysphagia are primarily based on qualitative and subjective observations and interpretations by a clinician or doctor. Based on the need for a quantitative, objective method for evaluating the severity, the TOngue Force Measurement System (TOMS) has been developed at the Clinical Research Laboratory of the G.F. Strong Rehabilitation Centre.

BACKGROUND

Early work in the measurement of tongue strength included Kydd (1) who measured palatal pressures exerted by the tongue at three discrete points using pressure transducers attached to palatal restrainers. More recently, significant work has been done on tongue force measurement by Reddy (2). Employing a head-restraining device to isolate the tongue force for measurement, he monitored tongue thrust forces with a cantilever beam transducer placed in the mouth. However, these and other previous investigations have exhibited various flaws such as insufficient number of data and lack of standardization in measurement protocol and setup. As a result, TOMS has been developed to address these deficiencies.

METHODS

Setup

TOMS, as illustrated in Fig. 1, consists of an aluminum cantilever beam transducer with two active strain gauges and two temperature-compensating dummy gauges in a full Wheatstone bridge configuration. The beam may be rotated to measure tongue forces in any of three directions (up, left, and right). A small tongue cup is located at the end of the beam for consistent positioning of the tongue, thus ensuring the measurement of a point force. The transducer is enclosed in an adjustable polypropylene mouthblock designed to accomodate the wide range of bite sizes encountered during testing. The mouthblock employs dental impression putty inserts to obtain proper fit and consistent placement in the mouth. The weight of the transducer/mouthblock assembly is supported by a frictionless ball joint that allows for free movement of the head, and thus, the specific measurement of tongue thrust. The recorded force signal is directly interfaced to an IBM PC/XT microcomputer for data acquisition, processing, and immediate visual and/or audio feedback to the subject.

Procedure

15 normal and 5 dysphagic patients were tested for their tongue strength in the three directions as mentioned.

During the initial session, the mouthblock was first adjusted to yield maximum contact between the dentition and the block. At this point, a set of four dental impressions were created for the individual to provide a custom fit between the mouthblock assembly and the specific mouth geometry. The measurement protocol consisted of three sets of force readings in each direction. A predefined target level of tongue thrust was achieved and maintained for each reading lasting 5 seconds. The specified target level was appropriately chosen to motivate the subject in reaching the target. Audio/visual cues from the computer indicated the start and the end of data acquisition session. A resting period of 30 seconds was provided between readings to prevent the onset of fatigue.

RESULTS/DISCUSSION

Fig. 2 shows a typical set of tongue force curves (left direction thrust) for both, a normal and a dysphagic subject. A significant, nearly an order in magnitude difference was observed between the normal and dysphagic force levels. The force levels generated by dysphagic patients also were found to vary according to their stages in rehabilitation. Variability in human factors such as mental and/or physical fatigue, lack of interest and tongue slippage accounted for the fluctuating force levels. The within-day and day-to-day repeatability of the results were tested using two factor analysis of variance and intraclass correlation coefficients (ICC), and the results were found to satisfy the repeatability criteria ($p < 0.05$).

TOMS' capabilities were greatly enhanced by its optimization for comfortable fit and customized reference positioning for each subject. Instantaneous computer graphic feedback were found to increase the subject's interest during testing. Consistent force data was readily obtained once the subject became familiar with the measurement protocol. Individual target setting personalized the test, making it more easily understood and focusing the task presented to the subject. All these features ensured that TOMS' results would allow the accurate diagnosis and assessment of a subject's tongue strength, and make TOMS a potentially, benefical treatment tool.

CONCLUSION

A device has been developed to quantitatively measure the tongue strength of individuals for the diagnosis and assessment of oral phase swallowing disorders. The statistical analysis of the data from 15 normal and 5 dysphagic subjects has confirmed the repeatability of the test data and the system reliability.

Future Work

Tongue force measurements using TOMS are presently underway to investigate the effect of fatigue on tongue strength in both, normal and dysphagic subjects. In order to study real swallowing processes, a measuring system is being developed to monitor the full palatal pressure distribution during the oral phase.

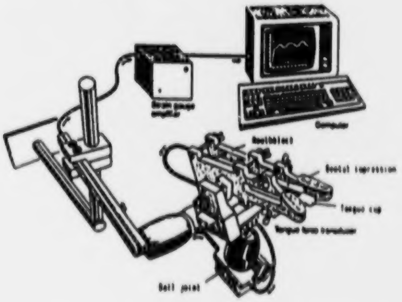

Figure 1. Components of TOMS.

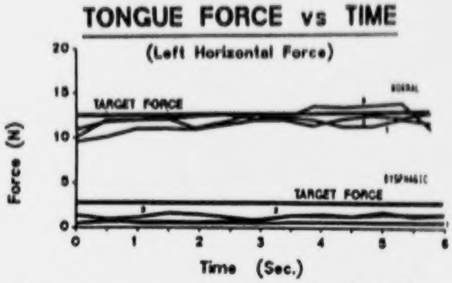

Figure 2. Results of Three Readings for Normal and Dysphagic Subjects, Left Direction Thrust.

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P3.33

THE DEVELOPMENT AND CLINICAL EVALUATION OF A NEW TOOL (C.L.E.M.S.) FOR THE MEASUREMENT OF LIMB VOLUMES

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ABSTRACT

In the past, attempts to determine an optimal management strategy for limb edema has been limited by the lack of an accurate clinical tool for quantifying limb edema. The development and evaluation of a new tool, the Computerized Limb VolumE Measurement System (C.L.E.M.S.) is described. The shape and volume of a chosen limb segment is rapidly measured by C.L.E.M.S. independent of subject position. C.L.E.M.S. was shown to be both valid and reliable as compared with water displacement. The tape measure method of measurement was shown to be invalid.

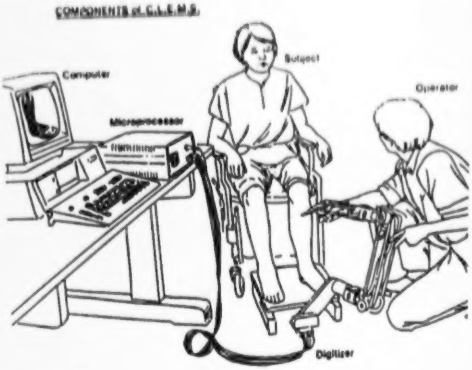
INTRODUCTION

Limb edema is present in the rehabilitation setting as well as the acute care setting. It can effect rehabilitation outcome and length of stay because of the slow healing of edmatous tissues (1). In the past, there have been many attempts to study various management strategies for limb edema. These have been limited by the lack of a valid, reliable, rapid, non-invasive, clinical measurement tool. C.L.E.M.S. (Computerized Limb VolumE Measurement System) has been developed for the measurement of limb volumes and meets all of these requirements. C.L.E.M.S. has three parts:1) a digitizer with optical encoders, 2) a microprocessor and 3) a personal computer. The shape of the limb is determined by the mathematical best fit to the data streams from the digitizer at each 1 cm cross section along the limb. The graphics portion of the software allows the operator to rapidly view the computer generated image of the digitized limb segment to check for errors. C.L.E.M.S. has the capacity of measuring the full length of the leg even though below knee segments were used in this study. The limb can be traced in any position of subject comfort as long as the subject is still (see Figure 1).

METHODS

Validity and reliability studies were completed on a single, average size plaster of paris leg and 5 normal and 5 edematous legs. The diagnoses of the 5 edematous patients varied but they all had neurological injury. None of the 5 subjects had a history of either central or peripheral vascular disease. Validity studies were completed by sequentially measuring the leg, from the knee down, first in a standard water displacement tank, then with C.L.E.M.S. and finally with a tape measure using the the equation for a truncated cone (2,3). Statistical analyses were completed using the Systat t-test and ANOVA.

Figure 1.



RESULTS

The graphics display of C.L.E.M.S., although intended merely as an operator check, compares closely with actual photographs of study legs (See Figure 2). The statistical analyses for validity showed a significant agreement between C.L.E.M.S. and water displacement volumes. The degree of significance is much greater in plaster legs and in legs of subjects with flaccid paralysis than it is in normal subjects or those with spasticity or partial denervation. This suggests that slight movement during the digitizing process would account for some of the differences seen. Pilot data on a single, incomplete spinal cord injured subject indicates a significant shift in leg volumes with activity and position over an eight hour period of time. The use of pressure stockings reduces this volume shift.

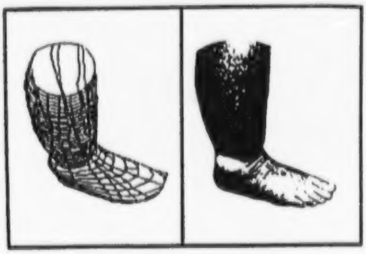


Figure 2. Graphics display of C.L.E.M.S. and photograph of the same edematous leg.

DISCUSSION

C.L.E.M.S. appears to be both valid and reliable. It has It has obvious advantages over the water displacement method (speed, ease of measurement, length of the limb segment which can be measured and position independence). The tape measure and the equation for a truncated cone were found to be invalid. This may be due to the inability of the trucated cone to accurately model the human shank, ankle and foot. Both our pilot data and data from other studies (4) indicates a need for further study on the effect of activity and position on lower limb volumes over time. The changes seen in our pilot data are large enough to confound any treatment efficacy studies that do not control for these factors.

CONCLUSIONS

A new tool for the measurement of limb volume has been developed and clinically tested. C.L.E.M.S. is a tool that is accurate, valid non-invasive and rapid. It can easily be used in the clinical setting for measuring lower limb volumes. The tape measure and the equation for a truncated cone is not an accurate representation of lower limb volume. There appear to be a number of factors affecting lower limb volumes. Pilot data suggests that time of day, position and previous activity may alter lower limb volumes significantly. Future studies will examine the effects of pumping, medication and pressure garments on lower limb volumes.

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THE ROLE OF THE STRETCH REFLEX IN GAIT

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The explicit role of the myotatic reflex in walking and running and in error-correction during human locomotion is a subject of debate. The implicit role of the monosynatpic reflex in error correction (*i.e.*, stepping over objects and avoidance of trips and falls) may operate in concert with polysynaptic pathways and central pattern generators of the spinal cord. Our research suggests that the development of spinal cord connections which allow the normal adult-like myotatic reflex pattern may be a fundamental requirement for the acquisition of normal locomotor skills. The presence of the myotatic reflex may not be a necessary requirement for the persistence of normal gait patterns in childhood and adulthood. Excessive levels of reflexly-evoked agonist and/or antagonist EMG activity may play a contributing role in modulating the patterns of gait with respect to the available joint range of motion, speed of movement, or the performance of complex flexion-extension synergies.

Studies of myotatic reflexes and gait in early childhood, aging, and neurologic disease have identified the following:

[1] Locomotor skills in normal children do not develop until the normal adult-like pattern of reciprocal inhibition is seen in the tendon jerk reflex, and reciprocal excitation is absent (in reciprocal excitation, EMG activity of agonist *and* antagonist muscles are simultaneously evoked at monosynaptic latencies and comparable amplitudes).

2] Children with hyporeflexia and hyperreflexia have impaired gait (*i.e.*, abnormal joint angle and velocity profiles). Tendon jerk reflexes are absent in a 4-year-old child with Charcot-Marie-Tooth disease (*i.e.*, peroneal muscular atrophy, a genetic motor and sensory neuropathy), and her gait pattern is impaired. A second child with developmental delay following a premature birth, is hyporeflexic by clinical examination, and his stretch reflexes have a delayed onset time (50 ms); he has failed to develop normal rhythmic locomotor skills by the age of 6. A 6-year old child with spastic diplegic cerebral palsy has hyperexcitable stretch reflexes on the left side and "reciprocal excitation" on the right side. She lacks the usual flexion-extension synergies at the hip, knee, and ankle during gait on both sides.

[3] "Successfully aging" adults (*e.g.*, those individuals who are physically active and who are not known to have neurologic or orthopedic disease) do not have definitive gait abnormalities. Tendon jerk reflex studies evoke a range of responses, including absence of the myotatic reflex, reflex EMG patterns like those in normal young adults, hyperactive reflexes, and "reciprocal excitation."

The explicit role of the myotatic reflex in rhythmic locomotor movements requires further study, with respect to changes in the reflex during early development, as part of the aging process, and in patients with neurologic disease. As previous research has determined, myotatic reflexes may be inappropriately activated during voluntary movement in patients with spasticity, and this may result in preferentially slow movements and cause difficulty in executing certain velocity-dependent flexion-extension patterns in gait. Areflexia or hyporeflexia in early development apparently are also related to gait abnormalities. This causal relationship requires further investigation.

The roles of monosynaptic and polysynaptic reflexes in early development and as part of the aging process need to be identified in error-correction on rough terrain, and to prevent stumbling and falling.

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P4.1

ANALYSIS OF VOICE PROCESSING FOR THE CONTROL OF DEVICES TO AID THE DISABLED

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ABSTRACT

The use of voice processing as a user controlled input to activate devices to aid the disabled was studied. Various voice processing hardware and software systems were analyzed in terms of accuracy, training requirements, processing speed, ease of use, and flexibility. The efficacy of such systems for various physical and cognitive disabilities was analyzed. In addition, the requirements of additional user/device interfaces for voice activated systems were studied.

INTRODUCTION

Until recently, voice processing systems were not a realistic mode of controlling devices to aid the disabled. Such systems were expensive, required excessive computational power, were difficult to use, required excessive user training, and were inaccurate and unreliable. However, recent advances in computational speed and power as well as microelectronic design has resulted in the development of several new technologies including that of voice processing.

Several commercially available voice processing systems have been developed and marketed for a variety of applications. Many of these systems have been targeted for an office environment. However, a few have been utilized for industrial, military and rehabilitation environments. Manufacturers of voice processing systems include Votan, Vocalink, Dragon Systems, Microphonics, Techmar, NEC, ICS, IBM, Texas Instruments, and Kurzweil. These systems operate in the telephone bandwidth of 300-3300 Hz. They operate as speaker dependent, single word (discontinuous speech) processors with vocabulary sizes of as little as 50 to as large as 1000 words. A vocabulary set is developed during a user training session where word templates are created for later matching of spoken words during the operational phase. The template creation and subsequent matching is usually accomplished by spectral analysis techniques. Voice processors act as keyboard emulators in a computer in that a recognized word substitutes for a keyboard entry into a computer.

There are several advantages to the use of voice processing in the control of rehabilitation devices. These include hands free control (which may be vital for quadraplegics or individuals with severe motor disabilities), rapid processing and control, conceptual ease of use (during operational phase), requires little effort by the user, and is a natural form of communication for humans.

There are also various disadvantages to the use of commercially available voice processors. These include the requirement for repeatable word patterns between training and operation, the inability to cope with ambient noise, and inadequate interfaces to rehabilitation devices.

METHODS

Various speech processors were analyzed for accuracy, processing speed, training requirements, ease of use, flexibility, immunity to background noise, and ability to interface with computer driven devices. The Dragon Systems Voicescribe-10 system was chosen as the optimal system which best met all of the above conditions.

This system was installed in a Zenith AT class microcomputer for analysis in controlling a mobile robot. The computer also contained a Metrabyte Dash-16 analog/digital/analog conversion board which sent voice activated signals to control the robot operation. Studies were conducted to determine the efficacy of voice control of robots in comparison to manually operated joystick control. In addition, noise immunity studies were performed as well as tolerances to variations in speech patterns.

RESULTS

The initial studies involved the tolerance of the voice system to ambient noise. It was determined that the noise of the robot as well as other external sounds could interfere with the accuracy of the voice processor. Thus, two ambient noise reduction systems were designed: a center clipping system for elimination of continuous (broadband) noise and a filter bank network for elimination of periodic noise. These were needed because the signal to noise ratio requirements of the voice processor are greater than that of the human ear.

The analysis of speech variations during voice processing resulted in the conclusion that accuracy of the system was extremely dependent on the repeatability of voice commands in the tone and spectral content of those words created during the training session. It was not necessary that the uttered sounds be words, merely that the sounds be repeatable between the training and operational phase.

The Dragon System voice processor allows a 0-100 scale for discretion of sound matching. This allowed the system designer to tailor the speech system to the ability of the user to match the training sound templates. In addition, the Dragon System board had a large vocabulary which allowed a greater range of word-like sounds to be stored. This was necessary since many disabled individuals might not be able to speak recognizable words. The voice processor would merely determine the closest word in its vocabulary which nearly matched the uttered sound of the user.

The comparison of voice controlled robot function vs joystick controlled operation was conducted over a controlled layout of robot motion and task assignments. Results for normal individuals indicated that voice controlled operation produced total task completion times which were similar to that of joystick controlled operation. However, there were some difficulties encountered when voice commands were used to control fine or detailed grasping tasks by the robot. The delay in robot function after a voice command was slight (approximately 0.1 seconds). However, when executing very fine grasping commands or very small movement commands, this delay was sufficient to cause some overshoot of the robot.

CONCLUSIONS

It was seen that the Dragon Systems voice processor was the best of the commercial systems for operation of devices such as robots. However, there was a need for additional ambient noise processing to allow this system to operate accurately in the control of a robot or in a relatively noisy environment.

The voice controlled operation of a robot was as rapid as that by joystick control. This is significant for those disabled individuals who cannot operate a joystick or other manually controlled device. In addition, the system could be tailored for word-like sounds, not merely for specific words. This is significant for those disabled individuals whose speech is limited in that they cannot produce distinct or recognizable words.

However, the use of voice control for fine motion of robots or other devices is limited. It is apparent that there is a need for additional inputs to produce fine motor control of some rehabilitation devices. These inputs may be autonomous in operation, but must be easily linked to user activated inputs, such as a voice processor. It is clear that a combination of voice processing and other autonomous input systems offers a flexible alternative for the control of augmentative devices for physically and cognitively disabled individuals.

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P4.2

TELEPHONE RECEPTIONIST SYSTEMS FOR PHYSICALLY HANDICAPPED INDIVIDUALS

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ABSTRACT

Two system have been developed allowing physically handicapped individuals to train as telephone receptionists.

BACKGROUND

An occupational therapist requested a system allowing a voice output communication aid (VOCA) user to train as a telephone receptionist. A system was constructed consisting of the VOCA, telephone switchhook control, monitor speaker, public address system, tape recorder, and interface circuitry.

An overall block diagram is shown as figure 1.

An initial prototype using toggle switches, geared for one particular client was not completed when staff decided a more general solution was desired. An electronic circuit provided features to ease system use. For example, the tape recorder can be turned on only when a call is in progress, and is shut off when the phone is hung up. Secondly, the P.A. system cannot be turned on while the tape recorder is running.

System operation is as follows;
When a call is received, the receptionist :

(1) Lifts the telephone switchhook to answer the call.

(2) Uses the VOCA to tell caller "Hi, this is___ from the__department, I am using an artificial voice, with whom do you wish to speak?"

(3) Connects the VOCA to the P.A. system and pages the desired individual.

(4) If the individual is present, the receptionist has no further duties, and hangs up once the individual takes the call. If the callee cannot come to the telephone, the receptionist connects the VOCA to the telephone, turns on a tape recorder and says "___" is not here now, please leave a message".

(5) After the caller leaves a message, the receptionist hangs up the telephone, automatically shutting off the tape recorder.

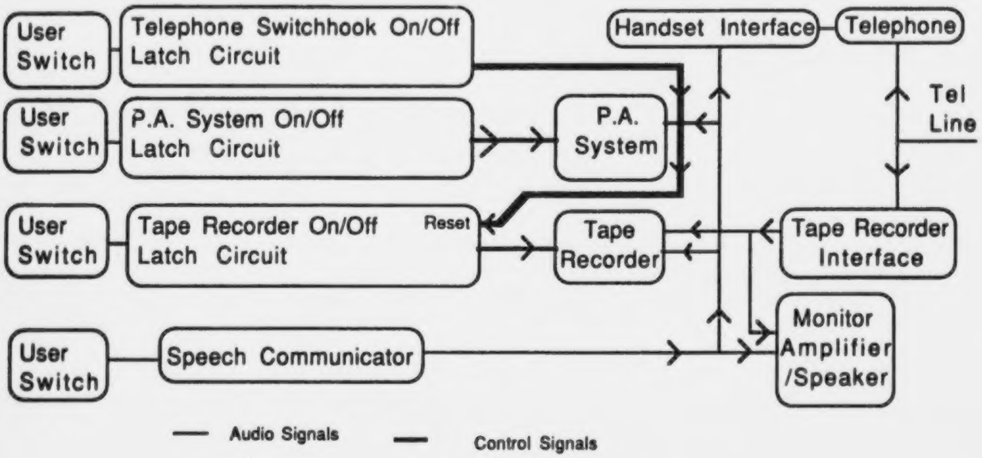
User Switch
Telephone Switchhook On/Off Latch Circuit
User Switch
P.A. System On/Off Latch Circuit
User Switch
Tape Recorder On/Off Latch Circuit
Reset
User Switch
Speech Communicator
Handset Interface
Telephone
Tel Line
P.A. System
Tape Recorder
Tape Recorder Interface
Monitor Amplifier /Speaker
Audio Signals
Control Signals

Figure 1 Telephone Receptionist System Block Diagram Using Electronic Communicator

While the present version of this system requires use of three switches in addition to the VOCA control inputs, it is possible that future versions could use the environmental control capabilities available on some VOCAs.

Due to delays inherent in row-column scanning, it is anticipated that receptionists must be able to control their VOCA using direct selection or directed scanning.

System for a blind, vocal user

A second occupational therapist requested a system allowing Yolanda to answer the phone for a unit coordinator. Yolanda is a gregarious verbal, blind client with no functional hand use.

She is 30 years old, and has lost skills throughout her lifetime due to her hydrocephalic condition. She has become increasingly dependent on others to meet all her needs.

A modified version of the previous system was constructed using a microphone input and two sip-puff tubes. Sipping on one tube will alternately connect and disconnect the telephone, while puffing on the same tube will alternately turn on and off a tape recorder allowing callers to leave messages. The second tube will control the public address system to make announcements throughout the building.

While this system is a new experience for Yolanda and her interdisciplinary team of professional support staff, it has stimulated a more cooperative and cohesive effort in establishing goals and objectives to be carried out with Yolanda across disciplines in an effort to become a more productive, self satisfied, contributing adult in her daily routine.

Some of the therapeutic goals which are being carried out to maximize Yolanda's effectiveness with the telephone answering system are:

(1) Improve sequencing of task steps.

(2) Increase attention span.

(3) Improve auditory memory.

(4) Increase breath support for greater volume during speech.

(5) Improve articulation through;
    (A) Increasing capital flexion which will result in a more tucked chin position.
    (B) Decreasing retraction of facial muscles which will increase lip mobility.

(6) Improve decision making skills.

(7) Increase vocabulary for telephone skills.

(8) Increase knowledge of telephone manners.

CONCLUSION

It is felt that use of these systems will give Yolanda and others some independence and self esteem. Being able to serve as a telephone receptionist can demonstrate to others that everyone has a contribution to make to the people around them.

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P4.3

SPIN-ART BY SWITCH CONTROL

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ABSTRACT

This paper details a spin-art machine for severely disabled individuals. It was built as a student project at the request of therapists at a residential facility.

BACKGROUND

Spin-art is an artistic technique whereby paint is dropped on spinning surfaces such as paper or cloth, creating circular patterns with unpredictable splatters. An art therapist and an occupational therapist, asked if it would be possible to build a large switch controlled spin-art platter. The rehabilitation engineer thought it possible but questioned the limited nature of client involvement, controlling only the spin motor. Instead, two separate systems were envisioned. The first, for users with moderate motoric involvement would have a "trolley" positioned over the spinning target. Three nozzles mounted on the trolley would be connected to three squeeze bottles via flexible tubes. These squeeze bottles would be placed for user control and would force three colors of paint to drop on the target. A mechanical crank would control in and out radial movement of the trolley.

A second system for severely involved users would have a motorized trolley connected to two client switches, and three electric paint valves controlled by three other switches.

After preliminary design requirements were established, a mechanical engineering professor asked for student projects.

The design requirements given to the class follow:

(1) Ability to paint t-shirts and sweat shirts.

(2) Ability to control the spin motor by a low voltage switch connected through 1/8" phone jacks. A latching circuit should be used to allow the user to alternately turn on and off the spin motor.

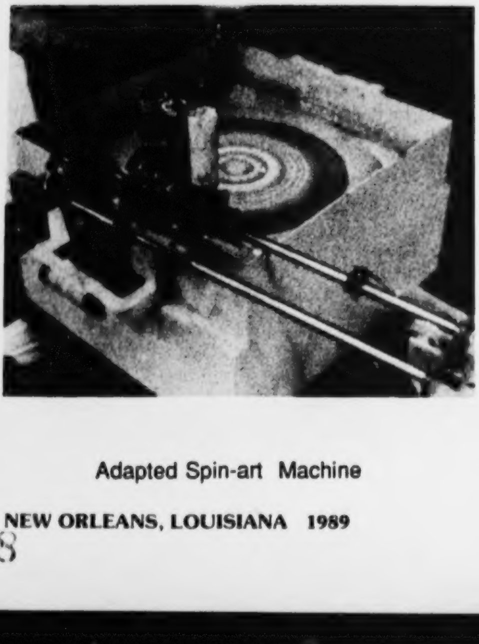
(3) A trolley across the radius of spin would have nozzles for three paint colors. This could take two forms:

A. For the less involved clients, movement of the paint nozzles across the radius could be controlled by a hand crank or other hand control. Paint would be applied by squeezing bottles placed in front of the user. The bottles would be connected by flexible tubes to the nozzles.

B. For the very involved clients, trolley movement would be motorized, and paint applied through electric valves. These five actions would be controlled by user switches plugged into 1/8" phone jacks.

(4) The unit should be transportable by a toy wagon.

A group of four students agreed to complete a spin-art machine as their class project. During initial project discussions, timer circuits were added to limit the amount of paint that could be



Adapted Spin-art Machine

dropped in one switch activation. Students also added limit switches for the trolley motion. Because desired rotational speed was unknown, students incorporated variable speed into the design.

THERAPEUTIC IMPLICATIONS

This project has been a great success. When first discussed, it was hoped that the machine would provide an experience that would be positive and have a tangible result for our severely involved adolescent and adult population (mental retardation with varying degrees of cerebral palsy) . What occurred was far beyond this.

Because the machine can be operated by any switch currently used by our clients, no one is excluded from participation. Simple pressure switches that are operated by a hand, foot, or head motion, a pneumatic switch using a blood pressure bulb, tilt switches, and magnetic switches are all examples of what can be used. Some clients have their own switches which can be used or switches can be provided.

The portability of the machine, and the fact that it can be seen by a client whether that person is sitting in a wheelchair or lying in a bed, and the diversity of client population that can use it, all make the machine a wonderful tool for therapy. Clients that are less physically involved can use squeeze bottles instead of switches to paint the project.

Therapeutic objectives have included but are certainly not limited to: group interaction, turn taking, attention to task, visual tracking, task completion, improving self esteem, increasing forward reach of upper extremities, increasing pointing skills, improving head control, cause and effect relationship, and decision making skills (making choices about what colors to use, where to place those colors, and how much of each color should be used.)

One result that was not anticipated was the public interest in the finished t-shirts and sweatshirts. A group of school age clients has used the spin-art project as one means of earning money to finance their community excursions each month. They have had opportunities to participate in community arts and crafts shows; setting up the booth, and handling the money taken in. These students have also filled orders by individuals in the community for gift giving during the holidays. They also were able to make gifts for family members and friends. While it started with painting pictures on paper, it has expanded to articles of clothing, such as t-shirts, and sweatshirts (allowing clients to wear their own creations), pillow cases, and wall designs. The therapist is only limited by his/her own creativity.

CONCLUSION

This project has provided an artistic and recreational opportunity for individuals otherwise unable to participate in the painting of t-shirts. It is expected that similar machines will be constructed for other locations in the state.

ACKNOWLEDGEMENTS

The authors would like to thank University of Oklahoma Professor Bill Upthegrove and his mechanical engineering students Roger Jessup, Craig Meier, and Chris Wenner for turning this idea into reality.

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P4.4 USING A TOY TRAIN SET WITH PHYSICALLY IMPAIRED STUDENTS

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ABSTRACT

This paper describes an electric toy train set constructed to allow active access by one to four non-ambulatory, severely physically challenged individuals.

BACKGROUND

A train set was donated to a special education teacher, who has worked exclusively with students who were nonambulatory and had severe physical limitations.

Instead of merely setting up a passive activity, the teacher asked if it would be possible to set up the project such that students could operate the train using switches. It was decided that the track loop would be divided into four electrical sections, allowing more than one student to participate.

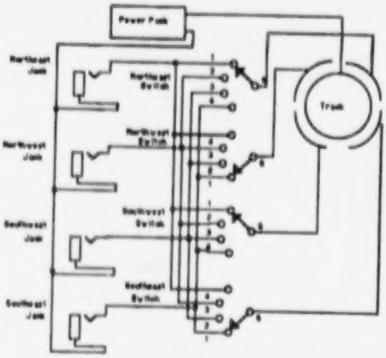
For educational purposes, the train set was constructed around a miniature community based on the nearby city of Pauls Valley. City streets were laid out in geographically correct placement. Educational staff photographed familiar community establishments and other points of interest. These photos were glued to small boxes and placed appropriately on the model. Community education was integrated into the students classes through weekly field trips into town.

PROJECT DESIGN

(1) A 4' X 8' plywood board was reinforced with 2" X 4"s and mounted on wooden sawhorses high enough to accomodate the large Gunnell wheelchairs used by some students.

(2) Rail insulators were placed in the track to break the layout into four sections. Track sections are controlled by student switches connected to the 1/8" jacks placed at the four corners in the supporting 2 X 4 's.

(3) A control box was built to increase the flexibility of the train set. Four slide switches allow each student to control from one to four of the track sections.



Switch Box Schematic

Adapted train set

FUTURE PLANS

(1) A volunteer group has agreed to raise money to purchase a Railscope by Lionel. This is a toy train locomotive with a miniature T.V. camera inside allowing the user to view the model scenery as if he or she was actually inside the engine rolling on the track. T.V. monitors replicate a black and white picture as if driving a real train. Trips may also be recorded on a Video Cassette Recorder. For physically challenged individuals this is one more opportunity for them to have environmental control.

(2) A proportional speed control may be added to the train set, providing opportunities for fine motor practice.

(3) A circuit may be built which senses when the train has left a track section, forcing a user to release and then reactivate the switch before the train can pass through the track section again.

RESULTS

The train project has produced some pleasant surprises and unexpected benefits. Visual tracking and auditory cueing are necessary for students to determine if the train is within their track section(s). Anticipatory behaviors and facial expressions are observed in many students with higher cognitive abilities. For example, one impatient student reached over to operate another student's switch because the second student had not developed acceptable switch activation promptness. As a result, taking turns, and other group social skills using switches have proven to be valuable project benefits. A final educational benefit has been the opportunity to learn more about the nearby community within a classroom setting.

ACKNOWLEDGEMENTS

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P4.5

AN IMPROVED DESIGN FOR AN ADAPTIVE HEADPOINTER

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ABSTRACT

Addressing a need for better fitting and improved aesthetics, a new design for an adaptive headpointer has been implemented. Such a device has been an essential tool for communication and educational programming. This design has been proven effective for students with cerebral palsy and related disabilities at the Massachusetts Hospital School.

INTRODUCTION

While safety and function will be overriding concerns in providing adaptive devices, a further look at student/patient utilization places more emphasis on design.

To produce a headpointer for many of our students, various materials as velcro, moleskin, helmet inserts and orthoplast had frequently been used. Through Project Access World, an interdisciplinary team effort at MHS to provide rehabilitation technology services, further steps were taken to improve existing designs.

METHODS

A general observation of the utilization of headpointers and their effective use has been ongoing. Through discussion and referral with teacher, speech and language pathologist, occupational therapist, rehabilitation engineer and student it was decided that an improved design for an adaptive headpointer would be necessary. The following specifications were considered:

1. easy adjustment and removal
2. adjustability of size
3. adjusting of pointer length
4. secured fit
5. compact storage in carry bag
6. conformity to headshape to facilitate accessing:
    a. mobility switches
    b. computer switches

SOLUTION

Through the input of our team occupational therapist, speech and language pathologist and our student subject, Scott, a functional prototype was constructed of the following component parts: (see Figure 1)

1. molded shell constructed from kydex
2. 1/4" closed cell foam rubber lining
3. 1" nylon straps
4. tri-glide rings for adjustability
5. aluminum clamp to hold pointer
6. polycarbonate rod

Fabrication

1. Fabrication process involved taking a cast of subject's head.
2. After pattern was cut, kydex material was heated and molded to head shape. As little material as possible was used to cut down on weight and bulk of shell.
3. Padded liner secured after shell cooled.
4. Straps were measured and cut to allow adjustability.
5. Pointer constructed of 3/8" polycarbonate rod.
6. Clamp is machined aluminum block and is bolted to kydex shell.

CONCLUSIONS

This design has provided a more secure fit and aesthetically pleasing look than previously used headpointers. Such a product is an inexpensive in-house solution to a problem that previously relied on commercially available devices or less durable solutions. This device has been used by 4 students at the Massachusetts Hospital School who have moderate to severe cerebral palsy. (see Figure 2)

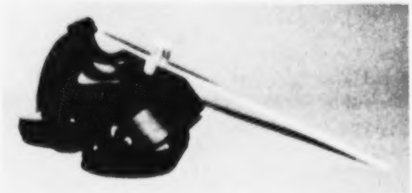

Figure 1. functional prototype headpointer

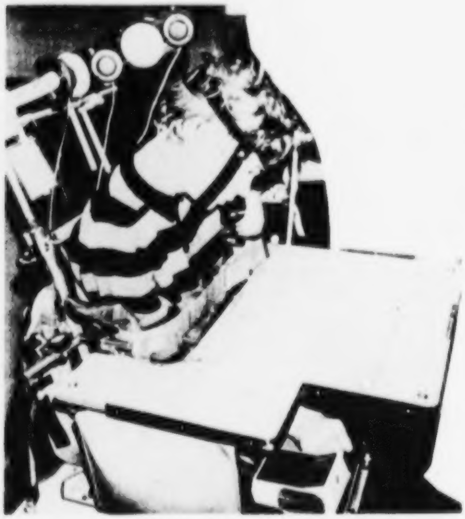

Figure 2. functional use of headpointer

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P4.6

CONSIDERATIONS FOR AAC DEVICE USERS WITH VISUAL IMPAIRMENTS

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ABSTRACT

Individuals who have the potential of benefiting from augmentative/ alternative communication may also require adapted techniques to accommodate decreased visual functioning or absence of usable vision. In either case, a primary consideration in the selection of an AAC device is the symbol system to be used by the individual.

INTRODUCTION

For the visually impaired AAC device user, the symbol system may be visual, tactual or auditory. The degree of visual impairment present will restrict the possible choices or require adaptations of the symbol system.

In the hierarchy of vocabulary type, progressing from tangible objects to traditional orthography, each step represents a greater degree of abstraction and fewer restrictions on communication. The use of abstract symbols and traditional orthography offers flexibility, standardization, and access to a wider range of commercially available communication systems.

Other considerations in addition to vocabulary selection include: the ability of the device to be placed at an angle, location, or height to accommodate the individual's physical and visual needs; the ability of the device to accommodate the symbol size or type needed by the individual; and the existence or appropriateness of the feedback system.

DISCUSSION

The individual with low vision

The symbol system appropriate for the individual with low vision, the size and nature of those symbols, and their arrangement can only be chosen after a careful assessment of functional vision. Following are sources of information: an educational interpretation of an ophthalmological report, detailed information regarding the individual's visual impairment and how it may affect functional vision, or a functional vision assessment by a teacher of the visually impaired or occupational therapist. Because the individuals are non-oral and possibly developmentally delayed, techniques designed for young visually impaired children may be more appropriate than those designed for older children or adults. The functional vision assessment will provide information concerning the distance the individual can see an object of a given size; in what position(s) the individual sees best; desirable lighting conditions; the existence of color vision, preferable color combinations; and the effect of medications, stress, and fatigue on visual functioning. The possibility of increasing visual efficiency by a sequential program of visual stimulation should be considered.

Accommodations for the low vision individual may include any or all of the following: selection of symbol size based on range of motion, functional vision, and cognitive ability; use of simple, clear, uncluttered illustrations; the elimination of glare-causing lighting and/or reflective surfaces; increasing the contrast between the symbol and the background ; and the utilization of appropriate color combinations and color cues.

The individual with little or no usable vision

A severe visual loss poses several interesting problems in the selection of device and vocabulary. Visual symbols must be translated into tactile symbols, which require more cognitive ability and effort to use than do visual symbols. The selection of meaningful tactual symbols is difficult, with extensive teaching of symbols required. The individual, unable to visually scan a symbol display, must either tactually scan or memorize the location of a given symbol. Visual feedback, useful to the communication partner, has little value to the individual. The magnitude of these problems depends on the age of onset of the visual impairment, the degree of cognitive ability of the individual, and the extent of physical involvement.

Tangible objects, either the object itself or a model of the object, impose limitations on vocabulary. and vocabulary size. Small representations, differing in sensory aspects from the real object, may not be recognized. The association between the object, the output, and the model may require direct teaching. A tactual vocabulary of textures has also been used successfully, but again, must be taught directly.

Raised line drawings are not direct substitutes for line drawings. One dimensional representations of visual concepts , they do not convey the same kind of information. Although the attachment of meaning to the symbol will not come automatically to the individual , the use of carefully selected and taught raised line drawings can form the basis for a communication vocabulary.

For an individual with high physical and cognitive ability, both abstract symbol systems and conventional spelling are possibilities. Raised Bliss symbols have been used with blind non-speaking adults; the Cheyne Symbol System of tactile communication symbols has been used with multiply-handicapped blind children. Both Bliss and Cheyne are based on a simplified visual representation of the item and again require extensive teaching. When conventional spelling is a possibility, either braille or tactual representations of letters, such as Moon type, make possible text-to-speech and the use of encoding to generate multiple utterances. The individual who has the capability to access a standard QWERTY keyboard may only require auditory confirmation of selections and tactual clues on the keyboard to assist in orientation.

When the individual is unable to direct select, auditory scanning may be the only possibility for communication. Auditory scanning provides access to messages in a serial, rather than a simultaneous, mode. The number of auditory scanning AAC devices is limited; because the individual is unable to visually anticipate a selection, cognitive demands differ from that of visual scanning.

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P4.7

Model of the Human Eye for ERICA Error Analysis

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A computer program was written to provide a dynamic model of the human eye. The purpose of this model was to provide substantive data to analyze the error inherent in the Eye-Gaze Response Interface Computer Aid, or ERICA. The ERICA system uses "real-world" data on eye movement to control its operation.

ERICA is a PC computer-based communication device for the disabled that uses a standard surveillance camera to monitor a user's eye-gaze across its display screen. The key to ERICA's operation is the "bright-eye effect," the human pupil reflects near infrared light: in an image obtained by the video camera with an IR-passing filter the pupil will appear as a bright orb. ERICA determines user eye-gaze by tracking the center of this bright pupil relative to the small, fixed, corneal reflection of the light source, referred to as the glint. The light source used is an LED mounted at the center of the camera lens.

At the beginning of a user's session ERICA calibrates this center of pupil to glint vector for various locations on the computer's display screen. With the user's head stationary, this calibration provides an area of confidence in eye-gaze determination within approximately a four centimeter radius of the actual eye-gaze location on the display screen situated two feet from the user.

Part of the error in gaze determination is due to noise in the video signal, the effects of which image processing has helped to minimize. ERICA encounters other problems, however, when the user's head drifts from its initial position. This lateral eye motion introduces significant error in ERICA's calibration. The effect of head motion is not easy to isolate since the corneal geometry alone introduces translational motion in the pupil center-to-glint vector. The radius of curvature of the cornea is less than that of the eye; as the eye rotates the glint is not an ideal fixed point but, rather, moves as the center of the curvature of the cornea is displaced.

A computerized model of the eye allows eye rotation and lateral head movement to be simulated with the effects of video signal noise removed. The model provides data for the analysis of ERICA's eye-gaze tracking errors and a base for its improvements.

Eye rotation and lateral head motion can be controlled in a window whose size and resolution are equivalent to that of a standard video camera. The eye is viewed at a user-input distance. A light source and its corneal reflections is also included in the model and can be positioned within space. With this model, ideal pupil center-to-glint vectors for known eye-gaze locations are calculated.

Initial testing has shown that eye-gaze determination can be made more accurate by changing the calibration. Originally, ERICA used a simple linear regression over two gaze points, with the x and y components of the pupil center-to-glint vectors treated separately. With no head-motion contribution, higher order regressions with interaction between x and y can decrease the area of eye-gaze determination by as much as sixty percent. In fact, accuracy can be shown past the limit of ERICA's imaging resolution. This requires more than two calibration points: at least eight for improvements to be seen. However, with head motion included, gains in accuracy are lost. The more complex the regression model, the more sensitive the tracking method is to lateral head motion.

Improvements in ERICA's eye-gaze tracking method, therefore, require compensation for head motion. The parameters from initial calibration must be adjusted when lateral motion outside of the range of that produced by eye rotation is detected. With a computerized model, the error produced by head motion can be isolated.

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P4.8

FEASIBILITY OF VIC FOR STUDENTS WITH LANGUAGE IMPAIRMENTS ASSOCIATED WITH AUTISM

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ABSTRACT

A feasibility study of language training using VIC software was conducted with 8 students at a school for children with autism. Experimental participants used VIC and controls played computer games. Most students enjoyed the computer sessions and VIC users made significant progress in training. Pre and post tests of language failed to show changes in language performance in either group. The primary finding of this study is the feasibility and appeal of this computer-based language technique with this population.

INTRODUCTION

Autism is a neurological condition resulting from a number of etiologies and marked by social and language deficits. Numerous studies have found many people with autism to have visuo-spatial abilities significantly superior to their verbal abilities.

VIC (Visual Communication) is a technique developed to study preserved communicative ability in aphasia (1). The aphasic population, as a result of their acquired left brain damage, are much more proficient at tasks demanding visuo-spatial ability than at tasks requiring language. VIC was designed to depend on visuo-spatial skills rather than language and auditory memory.

THE STUDY

A pilot study of the use of VIC as a language intervention for children and adolescents with language delay associated with autism was conducted at a Boston-area school for children with severe disorders of communication and behavior. The hypothesis was, first, that this approach would be appealing to these young people, because of the reduction of demand in areas typically difficult for them, including auditory language processing and face-to-face interaction, and also because of the potential for an experience of mastery and control which computer operation can offer, especially to people who experience a great deal of frustration in other areas of their lives, because of disabilities. Secondly, it was hypothesized that language production and reception training in this medium would have a positive effect on participants' overall language performance, as measured by tests exterior to the training.

SUBJECTS

Eight students diagnosed as autistic or autistic-like and with visuo-spatial abilities superior to verbal abilities divided into pairs matched for gender (male), age (mean for experimental participants14; for controls,13), academic/social skills (as represented by class assignment) and WISC-R performance IQ or Leiter score when available. These scores ranged from above-average to delayed (65 was the lowest performance IQ). Group membership was determined by coin toss.

Students' language was evaluated early in training and after 5 hours of computer use. Tests included the Northwest Syntax Screening Test, in receptive and an adapted expressive form, a test of sentence repetition, a test of understanding and producing prepositions and use of pictures to elicit descriptive language.

VIC TRAINING. Two different software systems were used. C-VIC is an augmentative communication system in which virtual cards are stored in "card piles" according to grammatical category, e.g., common nouns, verbs (4). E-VIC (Early-intervention VIC) (3) was designed for use with acute stroke patients with severe aphasia. The display can be simplified so that there is nothing on the screen except what the user is to attend to. Complexity can be added in small increments, as the user progresses through criterion-based training, by changing parameters displayed in a control window. Sentence windows can be specified in terms of physical size, number of items in a sentence and location on the screen, and up to three may be created.

Program (C-VIC or E-VIC) and training level were chosen on the basis of diagnostic assessment records and pre-test scores. The first experimental participant ceilinged on the highest level of training, so that novel tasks had to be created in order to challenge him. More severely language-involved students were chosen for the rest of the study.

Training was criterion-based, and students progressed to a level of greater complexity when criterion was met. Receptive and expressive use of the computer were alternated, with receptive preceding, to assure comprehension. A TV-game show format was used with "funny money", which could be redeemed for toy and snack prizes, offered as rewards for correct responses to questions such as "Where's the stuff?" (The response could require as little as selection of the correct noun "card" or as much as a several-card phrase including appropriately selected preposition and adjectives as well as noun.) Training levels can be summarized as follows:

Level 1: Procedural (control of mouse and cursor).
Level 2: Object-picture matching.
Level 3: Prepositions to indicate spatial relations.
Level 4: Selection of adjectives to distinguish among objects in prepositional phrases.
Level 5: Parsimonious use of adjectives on the basis of need to distinguish among possible referents of nouns.

CONTROL ACTIVITIES

The non-VIC-users played maze, memory and word games, followed the same schedule of computer sessions as their experimental pairs, and also got to choose prizes at the end of the sessions.

Sessions were twice weekly for 30 minutes for most of the subjects. The two youngest boys (aged 6 and 7) had 15 minute sessions twice a week, spread over 4 months. Total time in the program at the end of poast-testing was approximately 5 hours. Schedule and total time were constant within each pair of participants.

RESULTS

VIC TRAINING. The planned VIC training proved appropriate for 3 / 4 of the experimental participants. The second and third students entered the program at Level 2 and progressed to mid and late Level 4, respectively. (In further training, after the test results reported here, the third student completed most of Level 5). The 4th student, aged 7, entered at Level 1, and was in the early stages of Level 2 when training was terminated.

LANGUAGE MEASURES. The most representative language scores are those obtained using the NSST receptive test, in which the student is asked to point to the one of the 4 pictures which corresponds to an auditorily presented sentence. Experimental group mean went from 43% at pre-test to 44% correct at post-test, while control group mean was 45% on both occasions. These unchanging means hide individual variability. Only 1 youngster scored the same percentage correct on both occasions, while the others went up or down by several items. Tests requiring spoken output were even more subject to variability, since some students' willingness to talk was sensitive to mood fluctuations. Overall, no trend towards improvement was apparent in either group.

DISCUSSION

EFFECT OF THE INTERVENTION. No effect of the intervention was evident in the language test scores. While this may indicate that the intervention fails to affect students' language performance, it is also consistent with the interpretation that the time span was too brief and the number of subjects too small to observe an effect. The variability in test scores produced by control participants also supports this view. Initial testing was in fact postponed until two sessions of computer use had taken place, in order to assure students that computer use, not testing, would be the primary activity of these sessions, so that their cooperation would be maintained. The establishment of this expectation, and the familiarity which students acquired with the testers, was necessary to prevent an across-the-board improvement in test scores simply due to contrasting an unfamiliar context with a familiar one.

MOTIVATION. While the two most sophisticated students were interested in the "funny money" and enjoyed that symbolic reward more than the prizes they could redeem it for, the others were much less interested in the play money and quite uninterested in the non-edible rewards. Praise and smiles of approval were proudly received and seemed to be the biggest factor, along with the computer time, in supporting the students' participation. Cooperation in the testing was maintained at the price of promises to get back to using the computer as soon as possible.

INDIVIDUAL DIFFERENCES. The individual differences among this small group of young people were great. Language production was mostly echolalic for one child, largely absent for another and dysarthric to the point of severely reducing intelligibility for another. The group included an adept word-problem solver and a student whose need to select letters in alphabetical order greatly outweighed his interest in succeeding at the puzzle. Attention was a major issue for the two youngest boys, and it proved necessary to devise a special training program, based on a computerized version of Candyland, in MacPaint, using a transparent cursor which left a smile-face in response to mouse click, in order to have the children notice the relationship between their movement of the mouse and the movement of the cursor on the screen, and learn to control it. The students varied in the types of games they enjoyed; one youngster was happiest with programs that produced sounds, while another was disturbed by sounds. One impressed us with his superior performance in visual memory games, and another surprised us with his skill in solving word puzzles in contrast to his reluctance and difficulty with spontaneous language use.

UTILITY OF VIC. Use of C-VIC and E-VIC to support the language training pointed out positive features and limitations in both programs. In response to this, additional vocabulary storage and display features are being added to E-VIC, without reducing its flexibility and data management features. For the 3 older experimental group members, the programs were always enjoyable to use. The one student who was prone to become anxious and needed to use a notebook containing prompts for relaxation had recourse to this only at his initial session, and was able to remain or regain calm thereafter without it, although it was always present.

FEASIBILITY. The main value of this study was in the test of the feasibility of VIC use with these students, which was amply demonstrated. With the exception of one student, the 7-year-old experimental participant, who was sometimes happy to take the experimenter's hand and come to computer and sometimes on the point of tears at the prospect of computer time, the students came enthusiastically to computer session, independently, in the case of all but the two youngest, who were accompanied by the tester, participated with great engagement and were reluctant to leave, so that advance warnings of time up had to be given to give them a chance to prepare for moving on. The Macintosh computer, and the VIC programs in particular, seem to be adequate and even appealing vehicles of language experience for these students.

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P4.9

An Integrated Approach to Power Mobility and Communication Freedom

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ABSTRACT

A modular system providing operational independence, has been developed for a user who requires specialized switch accessing to a variety of assistive devices and environmental aids. The prototype system features a user operated system which allows the user to fully operate a power mobility device, make use of a custom communication board, operate an augmentative speech device, and access environmental controls as desired. The modular design of the system allows easy use of each element, independent of the others, while maintaining consistency of operation and access throughout. This paper describes the development of the integrated system for a client with cerebral palsy.

INTRODUCTION

The assistive devices market contains many devices addressing a specific need for a handicapped individual. A wide range of power wheelchairs and augmentative communication devices are available to meet mobility and communication needs. However, the reality of mass production does not account for all eventualities, and customization of the user interface(s) may be needed. Taken together, however, mobility and communication requirements raise a number of problems which standard devices are unable to resolve. Therefore it is becoming increasingly necessary, where integration of systems seems viable, to explore the relationship between integrated technologies, and the client's skills and needs. Client R.presented the Assistive Devices Program at the Thames Valley Children's Centre with such a case.

BACKGROUND

Pre-Assessment

Client R. has severe CP, is an experienced head switch operator of a scan controlled power wheelchair, and uses a tray mounted bliss symbol communication board proficiently.

Although adept at scanning with two head switches, R. experienced frustrations attempting to maneuver his chair because fine angular adjustments and tracking corrections are difficult when using a scanner. Durability problems with the head switches also occurred, resulting in operational problems and safety concerns. R's abilities warranted a more effective solution.

Assessment

R required a new power chair and was prescribed an Invacare Rolls Arrow operating on a 1551 switch control interface. This allows control of the chair by use of four direction switches. Tracking adjustments may be made by operating more than one switch at a time (eg. forward and left results in forward and to the left movement). During assessment it was found that, while R could not reliably operate any mechanical switches by hand (including power, speed, etc), gross hand movement would operate electronic capacitive switches. (These switches are operated by skin touch and require zero pressure.)

Concurrent to the power chair, an ACS/Epson Scan Pac was prescribed to augment R's communication. This device allows for single switch row/column scanning as well as joystick selection of programmable electronic speech. R could not operate the on/off button for the device, nor the paper feed button on the built in printer. The latter function was deemed very important in order to display the written message .

THE SYSTEM

Design Criteria

1-*safe and reliable operation of power chair, electronic speech device, or communication board, without facilitator intervention.*
2-*chair controlled by two capacitive switches operated by the hands, and two mechanical switches operated by the head*
3-*control of Hi/Low speed for chair*
4-*the speech device was to use the two switch scanning technique familiar to R, but be switchable to joystick mode for future use (the joystick mode can be emulated by the four switches)*
5-*The speech device must be available for use during feeding and other times and must be protected against spills and debris*
6-*a new light and tiltable tray was required to support the communication board (still required) and for daily activities*
7-*R. was to be able to advance the printer paper so that written messages may be easily seen*
8-*ability to control on/off of all devices*
9-*separability of the chair, speech device, and communication board in order to allow independent operation of any component.*
10-*additional features: ultrasonic environmental control, a horn, single switch jack for controlling miscellaneous devices (toys, etc)*

The Design

Tray- A plastic tray was constructed which housed the speech device within a shock absorbing cavity on the underside. From the top of the tray, a shallow well the size of the Scan Pac LED array was made. This array is used to indicate selection and is detachable from the speech device by a small ribbon cable. The bottom of this well was made from clear plexiglass allowing an easy view of the speech device in the cavity below while maintaining a protective barrier. A low weight lid was constructed for the well and hinged on the front. The LED array fits snugly on the bottom of the lid (secured by velcro, and therefore easily removable. Blissymbols were placed on the top of the lid and over the rest of the upper surface of the tray. The lid size is an integral number of blissymbols , and when lifted comes away at the borderlines. Therefore, when the lid is up, the speech device is clearly visible, and when the lid is down there is a flat usable surface which also has a full blissymbol board on it. Finally, the tray was provided with a manual tilt mechanism.

Opening and closing the lid is done by an electric linear actuator contained within the tray. Limit switches detect a fully open or a fully closed condition. An electronic circuit was designed to control the motor direction and overload. When the lid is obstructed, the circuit senses a current overload and reverses direction to the opposite limit position. Power (24V) is drawn from the wheelchair batteries.

Switches- Three capacitive plates have been recessed into the top of the tray. A capacitive switch circuit was designed based on a variable oscillator which reduces frequency when body capacitance is added to the circuit, by touching the plate.

New headswitches were designed which are an integral part of the seating insert headrest. These headswitches are aesthetically pleasing, and very rugged due to the use of industrial switches and sturdy mechanical stops which limit the throw. Shock is absorbed by foam padding and the whole headrest/switch is upholstered to match the insert.

Control System - A microprocessor based control was designed and constructed to operate the system. Power is applied by holding one of the head switches closed for at least 3 seconds. When the controller is powered up, it is automatically placed in the **CHAIR** operating mode at slow speed. This is indicated by a row of LEDs on the face of the control labelled:*VOICE/CHAIR,HORN,OFF,ENVIRONMENT, FAST/SLOW, and EXTERNAL.* Relays in the controller switch power on/off to the chair.

Two of the capacitive switches and the head switches now control mobility. Tracking adjustment can be done by operating more than one switch at a time. When the third capacitive switch (select) is touched, the control goes into automatic scanning mode with the direction of the scan controlled by the left turn and right turn switches. The scan proceeds through the possible selections until the select switch is touched again or the direction reversed. The selected function is carried out by depressing the "select switch".

A feedforward safety interlock system has been implemented to prevent any mishap, ie the final stage of the power chair control is only enabled while at least one of the four direction control switches is being activated.

Selecting the **VOICE/CHAIR** option when operating the chair,toggles the control to VOICE mode. Power to the chair is cut, a signal is sent to open the lid, and the voice device is switched on. The voice device is now controlled by the two head switches in a row-column joystick emulation mode produced through firmware. Direction changes are toggled by successive hit and holds on the switches. Alternatively, if the select switch is held at the time of power on, the remaining four switches control the scan directly. Maintaining a location on the selection array for a given time delay will cause a selection to be made. When in the two switch operation, activation of either capacitive switch (other than select) causes a printer advance. For four switch operation, simultaneous activation of a headswitch and a capacitive switch achieves the same result. Activation of the select switch will return the system to chair mode. (The lid is closed, power to the voice device removed, and power is switched to the chair.

When the Scan Pac is removed from the system and used alone it will not be equipped with a joystick emulator which the controller provides. To overcome this, a separate battery power hardware emulator was designed and provided with the system. Four switch operation is a standard access built into the Scan Pac.

The **HORN** selection produces a 3 second blast and then returns the controls to chair mode. The OFF selection switches power off to all functions (Scan Pac, power chair, and controller).

If the **ENVIRONMENT** selection is made; the four direction controls will operate different short ultrasonic bursts corresponding to four commercially available wall outlet control devices.

The **HI/LOW** selection activates chair mode and chair speed toggles between fast and slow.

If the **EXTERNAL** selection is made, a relay closes for the length of time that the select switch is held. This relay acts as an isolated power handling switch to operate any extraneous single switch operated device (ie toys) attached to the system .

A timeout feature has been built into the controls which switches off power to the system if five minutes elapse without any switch closures.

SUMMARY- Through the use of an easily programmable controller and five switches (three by the hands and two by the head), selection and full operation of a power wheelchair, a speech output device, environmental control modules, and a variety of externally switched devices is possible. Any switch type can be used as input, providing flexibility as the client's needs or skills change. The system is relatively cheap to produce (approximately $450 for the controller, and $400 for the tray and actuator), and functions reliably.

The system provides total user independence with a view toward communication and mobility freedom.

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VOCABULARY SELECTION AND EXPANSION STRATEGIES FOR THE NONSPEAKING TRAUMATIC BRAIN INJURED

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ABSTRACT

The nonspeaking brain injured are receiving increased services in the area of augmentative and alternative communication (AAC). In order to meet the unique needs and goals of this population, temporary and/or permanent AAC's must be customized and expanded. This presentation addresses selecting, organizing and expanding vocabulary and structuring system training to meet users communicative and interactive needs, as well as facilitate facilitate recovery of cognition, language and speech production.

These variables also influence how frequently and to what extent vocabulary and/or the augmentative system is upgraded. Similarly, when teaching the nonspeaking TBI to use augmentative systems, training sessions must be structured to accommodate and/or facilitate cognitive functioning. This presentation identifies systems typically provided for persons at each of the cognitive levels and provides strategies in selecting and expanding vocabulary for specific systems. Training guidelines at each of the cognitive levels will also be addressed.

The literature identifies various techniques in selecting and expanding vocabulary for individuals using augmentative or alternative communication systems. Needs assessments are frequently utilized to analyze the content or intent of communication, the environments where communication occurs, and an individual's communication partners. Such techniques have been utilized with the nonspeaking TBI, however other critical variables must be considered with this population. These include: the individual's cognitive level, as it relates to the Rancho Levels of Cognitive Functioning; the individual's cognitive and behavioral deficits; and the individual's cognitive, language and speech production goals.

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PERSONNEL PREPARATION AND SERVICE DELIVERY AT THE ALTERNATIVE COMMUNICATION TECHNOLOGY CENTER

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The ACT Center was developed in 1987 to help fulfill the need for service delivery and personnel preparation in augmentative and alternative communication in the central and northern areas of Michigan. Graduate students in speech-language pathology and audiology receive stipends for specializing in work with clients requiring enabling technology services. Services are provided in a wide geographic area within the context of a unique, cooperative model.

INTRODUCTION

The increasing need for personnel properly trained to deliver enabling technology services has been well documented. (1) A mail survey of speech-language pathologists in the Central Michigan area (2), identified the perceived augmentative and alternative communication needs of children. Over 400 potential candidates for service were identified and respondents emphasized the need for comprehensive evaluation of their students as well as pre-service and inservice instruction of therapists. A follow-up study (3) was conducted to establish the feasibility of developing an augmentative/alternative communication service delivery and pre-service education program at Central Michigan University.

The Alternative Communication Technology Center (ACT) was subsequently funded by The Governor's Research Excellence and Economic Development Fund of Michigan. A center-based facility was designed, constructed, and equipped within the same structure as the Communication Disorders Department of Central Michigan University. Since the initiation of direct service delivery in October, 1987, the ACT Center has delivered services to severely speech-language impaired children and adults within a 33 county area of the Upper and Lower Peninsulas of Michigan.

SERVICE DELIVERY MODEL

The service delivery model was developed in cooperation with local school districts and health care facilities. The initial project objectives were designed to: (a) identify the target population in Central and Northern Michigan, (b) develop a service delivery model for Alternative Communication (AAC) devices and services, (c) implement a service delivery model for AAC equipment and techniques, (d) enhance public and professional education, (e) develop marketable materials for use in AAC instruction, (f) increase employment opportunities for personnel and technology users, and (g) increase visibility of the project. The ACT Center combines a community and center-based program to deliver an off site client evaluation, therapy and follow-up, and professional education. The staff and graduate assistants work directly with the clients' existing professional team thereby accomplishing pre-service and inservice education as well as service delivery simultaneously. The center has a mobile unit and anticipates providing services to over 100 clients in the coming year.

PERSONNEL PREPARATION MODEL

The ACT Center provides stipends for graduate study and direct experience in AAC to approximately 12 students in speech-language pathology and audiology per year. An additional 40 to 100 students receive course work and/or indirect experiences. Competencies were established for students in intense study based on the American Speech-Language-Hearing Association Compentencies for speech-language pathologists providing services in augmentative communication (4) The state suggested Special Education competencies and the Directors' experiences in the described rural setting. All students participate in pre-evaluation case reviews which prepare them for direct client experiences. The overall goal is to provide the knowledge necessary to evaluate, use, and adapt existing and evolving technological aids and systems as well as fully understand client needs and capabilities in order to develop the basis for successful evaluation and intervention strategies. Major competencies are divided in increments across three levels of proficiency and students are evaluated as they progress on a five-point scale.

1-2 Beginning knowledge base and applications.

3-4 Intermediate knowledge base and applications.

5 Advanced knowledge base and application competence.

CONCLUSION

To date the ACT Center of Central Michigan has met and expanded upon initial program goals. Sensitivity to varying professional and client needs in different delivery settings has facilitated the development of a mutual support and cross-referral system while affording students with diverse clinical experiences. The efficiency and effectiveness of this combined service delivery and professional instruction model has increased the probability of continued growth and financial support of the program.

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ABSTRACT

A spastic/athetoid cerebral palsy quadraplegic was provided with increased independence through specialized electronics. The system allowed access to both an electronic communication device and a power wheelchair using the same control interfaces for operation.

INTRODUCTION

Increasing independence is a goal for all handicapped individuals. With the nonspeaking severely physically challenged population independence may only be minimally achieved. Two areas that have the greatest impact on facilitating independence are mobility and communication. Common control interfaces used in mobility are the joystick, chin control and pneumatic. However, many of our physically handicapped population do not have the motor capability to operate a power wheelchair in this manner. While some clients have been provided with custom interfacing for mobility, separate control interfaces have been needed to operate the electronic communication device. This results in problems with the number of control interfaces and mounting considerations. Independence has also been jeopardized by the necessity to have another individual change control interfaces from mobility to communication or vice versa. Recent advances in commercially available technology make it possible for this population to access both a power wheelchair and electronic communication system using the same control interfaces, thus increasing independence.

BACKGROUND

The client, David, was a 25 year old male with a diagnosis of spastic/athetoid cerebral palsy, quadriplegia. He was nonspeaking, nonambulatory and dependent for all activities of daily living (e.g., eating, writing, communication, mobility and hygiene). He was unable to use either his upper or lower extremities for any functional task. The most reliable control site was his head.

Results of a psychological evaluation indicated that David was of normal intelligence. He was a high school graduate.

Communication was primarily achieved through the use of a qwerty board, which was manually scanned by the listener using quartering system. David responded by indicating "yes" or "no". An upward eye gaze was used for "yes" and a gross head shake was used for "no". The Words Plus Equalizer (Grid Computer) was also used, but on a more limited basis. This was a result of concerns regarding safe portability and security from theft. It was therefore used as a stationary system within his UCP day program.

David was attending a program through United Cerebral Palsy and took a computer class. He had been unable to attend a State University because he was not independently mobile and had no funding for an attendant to provide mobility.

The only funding source was Medicare/Medi-Cal. The problems with these funding sources is that they will only fund a preset designated charge for wheelchair control systems. This charge does not accomodate specialized electronics. These funding sources also do not yet designate electronic communication devices, as a benefit of the program.

METHODS

Equipment

Results of extensive evaluations indicated that mobility could be achieved through the use of multiple control interfaces mounted on a headrest. With the appropriate electronics, it was further determined that these same controllers could be used to operate his new electronic communication device.

Funding

Due to the difficulties involved with existing funding sources, special donations were obtained from private donations.

Training

Mobility. Instruction was provided to develop the following skills:

1. How to stop the wheelchair, including both normal stopping procedures and emergency stopping.

2. When to stop, which involves anticipating the course of travel of other vehicles.
3. Planning the route which includes directional changes and different commands.
4. Learning to judge the width and depth of the wheelchair, its operating parameters and maneuvering capabilities.
5. Learning to adjust to different driving surfaces, such as concrete, grass and sand.
6. Learning to cope with the fear of helplessness in difficult driving situations.
7. Developing communicative body language to convey driving intentions to others.
8. Learning to identify when due to illness or fatigue driving should be delayed.

Communication. Instruction was provided to develop the following skills:
1. Multiple switch activation of the communication device.
2. A technical knowledge of the device operation.
3. Understanding of the device's method of encoding words and sentences.
4. Methods for selecting vocabulary to be programmed.
5. Application of the device's use for functional communication in a variety of settings.
6. Recognizing system malfunction to convey this to the necessary personnel.
7. Use of an emergency manual communication board to express specific information related to problems with the power wheelchair or communication system.
8. Ability to instruct residential staff on equipment care and maintenance.

RESULTS

The specialized electronics, which is commercially available proved to be an effective source for combining mobility and communication. David demonstrated the skills necessary to operate both his power wheelchair and electronic communication device in his environments.

DISCUSSION

The importance of training was demonstrated as significant. It needs to involve the client and primary caregivers. Many training sessions involved unreinbursed hours. This is an important area ignored by funding agencies. Therapists, durable medical equipment dealers, and manufacturers cannot bear the financial burden of time and services for installation of specialized equipment and extensive training for the severely handicapped client.

An unanticipated problem was the abuse that equipment generally receives in residential settings. Although key staff members were trained initially, their time constraints did not permit them to devote the necessary care required of the specialized equipment. In addition, because of the client's physical limitations he was unable to observe problems with equipment out of his visual range (e.g., bending of wheelchair push handles).

Funding constraints restrict repeated repairs. Therefore the burden of repair costs may prevent the client from continued use of his equipment. Thus defeating the original goal of increasing independence.

Prior to implementing a similar program, a repair fund also needs to be established

CONCLUSIONS

The importance of a continued support group for the client was demonstrated. Many changes are occurring within the electronics field and technology is allowing more disabled people a greater variety of opportunities. The successful transition from being totally dependent to a fuller participation requires a continuing effort on the part of the client, family or caregivers and therapists. This support group can provide technical upgrading information and can assist the client in maintaining positive motivation towards fully utilizing the equipment towards cultural mainstreaming.

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P4.13

INTEGRATING POSTURAL SUPPORT AND AUGMENTATIVE COMMUNICATION SYSTEMS: AN INTERDISCIPLINARY APPROACH

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ABSTRACT

Positioning is an integral part of the evaluation and selection process for alternative augmentative communication and plays a continual role in developing communication interaction throughout an individual's life. Finding positions that optimize augmentative communicative effectiveness in a variety of situations is a joint effort of the interdisciplinary team. This paper will discuss each team member's role in the process of providing positioning which incorporates alternative augmentative communication into the total postural support seating system.

Interdisciplinary Team and Postural Support

Historically the occupational therapist and physical therapist are the two professionals involved in positioning. However, when considering the total needs of the individual it is impossible to address this effectively without input from all the professionals on the interdisciplinary team as well as from the local personnel, family and the individual themselves.

Occupational and physical therapists continue to work closely to select an appropriate postural support system. They consult with other team members to help in this decision making process. Medical personnel will be most interested in the potential for improved skin care, respiratory and digestive function, and minimizing contractures. The classroom teacher contributes information regarding various positioning needs during academic and play activities. The local school personnel and/or family are vital in considering environmental demands and constraints outside the rehabilitation setting. The psychologist notes the effects of positioning upon cognitive development. The speech-language pathologist looks at the effects of the neruomotor impairment and various positions upon speech and non-speech communication efforts. The social worker assumes responsibility for identifying potential funding sources for the seating system.

Once the basic postural support system is decided upon, the rehabilitation engineer provides input regarding design and fabrication of the adaptations. The carpenter and seamstress contribute ideas for practical application, as well as actually constructing the necessary modifications.

Augmentative Communication and Postural Support

For some nonspeaking individuals, positioning may be the determining factor in making alternative communication possible. In order for the person to optimize their alternative augmentative communication system, it should be viewed as an integral part of the postural seating system. Factors to be considered when integrating the alternative augmentative communication (AAC) and postural support systems are:

1. What forms of AAC does the individual use, i.e. light tech, high tech, both?
2. What environmental characteristics/demands need to be considered? Will the communication aids need to be accessible across all environments? Are there situations when one mode of communication would be used more than another? Are there times when a cleared work surface is a priority?
3. What is the individual's mode of access for the communication aid? Are there any other components of the seating system that might interfere with this access?
4. Will the AAC need to be mounted along with other devices, i.e. power wheelchair joystick, environmental control? How can these best be incorporated?
5. What is the optimal position for the AAC when considering functional movement, reflex patterns and accessibility?
6. What would be the most durable and stable way of mounting the AAC?

Conclusion

Through the Division of Developmental Disabilities we follow clients routinely for review of positioning needs and updating of modifications as physical growth and changes in neuromuscular skeletal status dictate. Over time the process may involve various changes in modifications, or a completely different system, depending on the individual. As with other aspects of the individual's life, positioning is an ongoing process needing continuous observation and management. It is an integral part of the evaluation and selection process for augmentative alternative communication, and plays a continuing role in development of communicative interaction throughout the individual's life.[1]

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P4.14

EFFICIENT COMMUNICATION THROUGH EYE-GAZE.

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ABSTRACT

In the recent past several communication systems have been based on the eye-gaze of a disabled person. In this paper the design and testing is described of a similar system that allows almost unlimited head movements. In addition, a high resolution of the observation of the eye-gaze has been achieved in order to enable access to a simulated keyboard.

The system uses a NAC-V eye-camera and a communication board with 54 cells. Tests have shown a mean communication rate of 72 characters per minute for untrained subjects. 1.3% of the characters were incorrectly registered.

The influence of user experience and of the type of communication protocol on both the rate and the accuracy of the output are subjects for further study.

INTRODUCTION

In the past a considerable number of projects have applied different communication methods which can be used by persons with severe impairments of the motor function and speech. The majority of these methods is based on the observation of the eye-gaze with which an object, symbol or character is fixed (1, 2, 3). Some developments have led to an industrial prototype or product, such as a communication board, camera or computer interface.

However, two specific problems remained unsolved. First, the resolution of the eye-gaze observation is limited. For this reason most communication systems either have a limited "vocabulary" or a "two or multi-pass" protocol, thereby reducing the communication rate considerably. Secondly movements of the head are mostly not allowed or rather limited, which makes the device less comfortable or even unapplicable for some larger user groups (e.g. in the case of spasticity).

The present pilot study was aimed at the development of an eye communication system, with higher communication rate, and allowing the user almost unlimited movements of the head.

METHODS

To this end a NAC-V eye camera has been applied. The system consists of:

1. a mini camera connected to the forehead, registering the field of view on a TV monitor or video-recorder;
2. an infra-red system based on the cornea-reflection method, delivering a signal, superimposed on the previous image and indicating the eye-gaze in relation to the field of view. This way the symbol a person is visually indicating is continuously known. At the same time completely free movements of the head are allowed.

For testing and retesting, 29 healthy subjects were placed in front of a panel with 54 cells, containing numbers (in increasing order) or characters (in alphabetic order). The eye camera was strapped to the head. During calibration (max. 5 minutes) subjects were asked to look at markers at the top, bottom, left and right of the field of view.

Free head movements were allowed during the tests, in which subjects were asked

1. to point with the eye-gaze as fast as possible to the symbols, dictated at a given rate (3 or 4 seconds per symbol);
2. to "spell" a sentence at an imposed or at the highest possible and self-chosen rate. Although the system is designed to be fully automated for computer access, an additional signal has been applied for test purposes. During tests with a self chosen rate, subjects indicated verbally the character after it was found on the communication board.

The sequence of the tests was randomized. All tests were registered on a video-tape (field of view, indicator for eye-gaze, sound, timer) at 25 frames per second and analysed off-line.

Analysis of the tapes is carried out as follows. Per subject, the eye-gaze is observed during the search process of 5220 symbols. For tests at an imposed rhythm, the time interval was measured between the start of each verbal (dictated) signal and the definitive arrival of the eye-gaze at chosen rate delivered time intervals between verbal indication (by the subject) of subsequent characters. In addition an accuracy score (between 0 and 3) was added, depending on a correct response to the given task or the type of error (adjacent cell, cell not found, imperfect coordination).

RESULTS

Off-line observation of the tape indicates that untrained subjects can point to 54 symbols in the field of view without any limitations of the head movements and with an accuracy of 98.7%. The minimum time needed to reach a cell decreased from a mean of 0.81 seconds in the test to .77 seconds in the retest, indicating that a learning process can increase the communication proces significantly ($p < 0.01$).

Detailed analysis also showed a correlation of .82 in the test (and .87 in the retest) between the searching time and the distance between subsequent symbols.

In order to estimate the influence of the path length on the rate of communication, linear regression equations were derived from the tests. In addition an optimized table lay out has been calculated for the Dutch language. Altough tests have not yet been carried out, since an intensive training period is necessary to become conversant with the modified lay out, a mean search time per symbol of 0.71 seconds and a communication rate of 85 characters or 17 words per minute could be predicted.

DISCUSSION

The optimization procedure indicated above, only accounts for the distance between subsequent sybols. In addition, subjects can improve their technique of pointing to one symbol and moving to the next. Further study is necessary to quantify these training effects as well as the influence of fatigue. However, available results already suggest that the communication rate of the technique described in this paper is comparable with that of "one-finger-typing".

It is thought that the accuracy with which symbols are indicated can be improved both by more extensive calibration procedures and by an auditive feedback of a fully automated and real time communication process.

In this way it is hoped that this new technique will contribute to a fast and efficient communication and computer access for severely handicapped persons.

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P4.14A

ASSISTIVE TECHNOLOGY: CREATING A PARENT NETWORK

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ABSTRACT

There are numerous support groups for parents who have children with disabilities, both on the national and local levels. However, parents of augmentative communication users are faced with unique challenges at home, in schools and within their communities and therefore, do not feel that their needs can be fully addressed in the generic support groups. As a result, a parent structured network, P.A.C.T.(Parents of Augmentative Communication Talkers) was formed in Atlanta, Georgia to serve as a supportive, social and an educational environment where the issues and concerns specific to children using technology related assistance could be discussed. Outlined below is a working model of a parent support group which is based on the P.A.C.T. network, and may be used as a prototype to assist and encourage those interested in providing complete services to their augmentative communication consumers and their families.

BACKGROUND

The three founders of the network included a parent of an augmentative communication user, a speech pathologist, and an assistive technology product representative. Their varied backgrounds provided insight into current issues which could be best addressed in the networking sessions. In addition, other topics for discussion were solicited from the attendees at the founding meeting and continue to be solicited on a regular basis.

DISCUSSION

The following provides an outline of the key elements and how they were addressed during the formation of the P.A.C.T. network. These general areas will most likely be encountered by others considering starting a group such as this.

Formation

Professionals working with augmentative communication users were informed regarding the formation of P.A.C.T. in order to solicit potential members. In addition, vendors were asked to contact families who have bought or were in the process of buying augmentative communication devices. As a result of these methods, plus parents networking with others, P.A.C.T. has an extensive membership and mailing list.

Structure

During the first organizational meeting those in attendance expressed a strong interest in forming a parent group and in it functioning as supportive, social, and educational for the parents, as well as provide occasional social gatherings for the children. It was also decided that the members, rather than the founders of the organization, would direct the group by providing suggestions, topics of interest, meeting dates and the format of the meetings. It was the parents' decision to alternate informational/educational meetings with social gatherings for both themselves and the children. Educational meetings provided speakers addressing: advocacy, state issues in augmentative communication, Minspeak and product development, funding, and assistive technology and services. A Christmas party and potluck dinners and picnic served as social gatherings.

Organizational Details

Central location. A central location was established from polling the geographical representation of the members. All meetings, with the exception of social gatherings were held at this location.

Officers. Officers were nominated and elected by the members within the first six months of the formation of P.A.C.T. The elected officers included representation from both founding members and parents.

Funds. It was decided by the membership that P.A.C.T. should assume the responsibility of payment for printing, postage and miscellaneous expenses related to meeting announcements. As a result, a checking account was established to retain funds received from membership dues and donations.

Public awareness

One major goal of P.A.C.T. is to increase public awareness through the submission of articles in local, regional and national publications to sustain and increase the membership of the P.A.C.T. network. In addition, the parents and the founders of this network hope to promote awareness of this model in order to stimulate replication in other states. To further meet this goal, an informational brochure was developed which describes the organization, its goals and purposes. Local television and newspaper coverage also aided in increasing awareness of P.A.C.T.

Replication

Another major goal of P.A.C.T. is to function as a prototype for replication throughout the state and nationwide. The success that we have experienced since the group was formed leads us to believe that not only is this a unique organization, but that it is also providing an opportunity for parents to share experiences with others who have similar problems, successes and needs. This model, begun with limited personnel and funds, has easily transformed into a significant and useful network for its members. Therefore, replication of this model should be an easy task for others interested in forming a parent support group.

CONCLUSION

In conclusion, the existence and overwhelming support of this organization provides evidence that a parent network which is specific to the utilization of assistive technology, has far too long been the missing link in the provision of comprehensive services to augmentative communication users and their families. A model has been presented which is easily replicable, and provides the means to empower the parents to better serve the needs of their children.

ACKNOWLEDGEMENTS

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P4.15

THE JOY RIDE

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ABSTRACT

A Power Wheels Jeep[1] was modified for use by orthopedically and multihandicapped children of Gorman Elementary School, Dayton Public Schools (DPS). The chassis and body were extended by the craftsmen of the sheet metal department (DPS), and the battery and switch controls were modified for remote control by the electricians (DPS). Both modifications proved extremely effective in transforming the vehicle to a wheeled mobility which could be used by all students.

INTRODUCTION

It is recognized that physically handicapped children often have distorted perceptions of spatial relationships and velocity. But to truly conceive of size, form and distance beyond their reach, children need to experience and control movement through space. Unfortunately, during their formative years, handicapped children are often limited in these movement experiences, or these experiences may be so over ridden with the exertion required to participate that what the children learn is only that they are exhausted after travel.

BACKGROUND

Several years ago, one of the co-authors had used a battery operated motorized ride-on toy vehicle to provide the opportunity for mobility for several severely multihandicapped children. Although that was a worthwhile project, there were limitations and therefore frustrations. One limitation was that only a few children were small enough or stable enough to be supported in the commercial seating. Secondly, the longed for independence in mobility for students was thwarted in that they had to be attended along the was since there was no way to safeguard against "crashes". Last spring (1988), that author, with several other teachers and therapists, applied for a grant to purchase and modify two motorized ride-on vehicles to be modified to accommodate various sizes of children and to be adapted electronically so that power could be controlled remotely for safety.

METHODS

The vehicles adapted were two Power Wheels jeeps. These were selected because they carried the largest load (advertised 80 pounds, but will carry more); had the widest chassis (23"); were powered by two six volt batteries that could be replaced locally. There was an attempt to purchase a ride-on vehicle that was operated by joy-stick, but Hedstrom manufacturing had discontinued manufacture of ride-on toy vehicles. There search for other commercially available ride-ons was unsuccessful. Power Wheels Inc. was very cooperative in answering questions about capabilities of their vehicles and can do some modifications at the factory.

Extension and modification of frame

The body was removed and chassis was cut at the center of gravity. Two extension lengths (9" and 13") were determined to accommodate the various body heights. Three quarter inch pipe extensions with three quarter inch rod inserts were placed under the "runners" so that by use of an allen wrench, the vehicles could be shortened or lengthened. Ten gauge sheet metal inserts were formed to the frame to be placed on the rods to provide for the body extension. All sheet metal was painted for rustproofing and appearance. Sandpaper adhesive nonskid strips were placed on the floor. The steering column was also modified by a pipe and rod extension that could be adjusted by an allen wrench. Velcro fastening seat belts were attached by recessed nuts. A final glorious touch for the students was the addition of a black high rounded foam rubber roll bar and two dice hanging from the "mirror".

Remote control

An MRC (Model Rectifier Corporation) Radio Control System[2] was installed with split wiring to the forward/reverse switch and the high/low switch) so that control could be remote or internal. (The reverse control was also modified so that use or non-use could be preset by the instructor/therapist.) This control system provides a receiver (2-1/8" x 1-1/2" x 3/4") of correct proportions to fit along side the batteries under the hood. This system also allows for control of two distinct switching systems. It also has a battery condition meter to monitor use.

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[1] Power Wheels, 5120 Investment Dr, PO Box 8601, Fort Wayne, IN 46898.

Specifications

Transmitter. Size 7" x 2-1/4"
Weight without battery 15 ozs.
Battery: Eight AA pen Dry Cells, nominal 12V or Eight AA Pen-Cells Nickel Cadmium 9.6V
Receiver. Size 2-1/8" x 1-1/2" x 3/4"
Power Supply: Four AA Alkaline Pen Cells or Four AA Nickel Cadmium Pen-Cells
Receiver Type: Superheterodyne, Double Tuned Front End IF Frequency 455 KHz
Weight 1 oz Antenna Length 38"

RESULTS

The final vehicles were, in appearance, souped up jeeps. But they provided much more opportunity for therapeutic mobility. All 70 orthopedically and/or multihandicapped students from preschool through sixth grade have been able to drive or ride in the jeeps. The more physically disabled children have been highly motivated to control the jeeps and now all have either controlled the steering or foot pedals. Sometimes the choice has meant that the fatigue factor is minimized. Both the sheet metal work and the radio control have survived the endurance tests very well. We are looking for a more durable attachment for the seat belts and a method to increase the efficiency of the steering column extension. The high rounded roll bar has been a real asset for securing the less stable students. It has meant that we have not been compelled to construct adapted seating, which means the students have a more "normalized" experience. We have opted for cadmium batteries, as the Alkaline charges dissipate rather rapidly.

DISCUSSION

The transformation of the jeeps gave many students the chance to control their movement through extended space. The design was straight forward and with the right materials quite durable. We are planning to improve on the model by developing joystick control, better secured seat belts, more efficient steering column, and adapted seating. The latter is largely in consideration of the handlers who need to lift the children in and out of the jeep.

CONCLUSIONS

We recommend this project to caregivers of orthopedically handicapped children as it is highly motivating, allows many children independent control, is reasonably inexpensive (less than $400.) and is reasonable to implement.

ACKNOWLEDGMENTS

We wish to acknowledge Dayton Public School for allowing us the time to pursue this project. We thank Mr. Lanasa, principal, for his moral support. And finally, we wish to recognize the students of Gorman Elementary School for being such excellent field testers.

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P4.16

Optimization of a Children's Mobility Aid, "Earth Scooter," for Playgrounds and Bumpy Grassy Terrain

SAN FRANCISCO STATE UNIVERSITY
REHABILITATION ENGINEERING TECHNOLOGY PROJECT
Joyce Knezevich and Diana Lion - Graduate Students

Abstract

The purpose of this caster project was to create a systematic approach for cart design. The three primary areas addressed were customizing fit, optimizing mobility on bumpy grassy terrain, and establishing a system of locating various components of a caster cart. For testing purposes, an adjustable adult-sized prototype was built. Results obtained with this cart were used in fabricating the child's caster cart. The result of this project is a step towards custom-fit caster carts to help maximize individual mobility potential.

Introduction

The design team researched current mobility aids and found that caster carts are widely used in the transition to wheelchairs for thousands of children in the United States who have lower limb motor problems. Several gaps in the design of available marketed caster carts were found. Adjustability, which has been utilized for state-of-the- art wheelchairs for a custom fit, has not yet been incorporated into caster carts. Also, most caster carts do not provide adequate mobility on bumpy outdoor terrain. No documentation has been found about how to systematically configure/locate the drive wheels, casters, and center of gravity of caster carts for various terrain and user specifications.

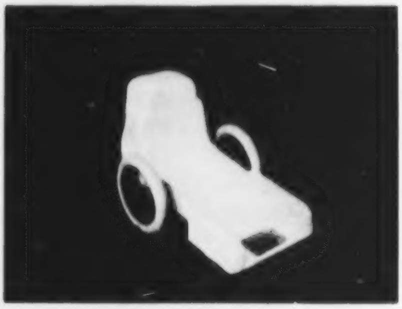
Methods

In September 1988 the design team met a 3-1/2 year old boy named Sean at his daycare center. Sean's primary method of mobility was scooting on his bottom with his legs held straight out in front of him. He wanted to move faster in order to keep up with the other children - especially outdoors.

After meeting Sean and seeing the bumpy playground at his school, it was clear that the available caster carts would have to be improved to meet Sean's needs. The design team found it difficult to evaluate and predict the effects that changes in the child-size caster cart would have on Sean's ability to move and propel. Therefore an adjustable adult-size caster cart was built as an experimental tool. The adult-size cart was ridden by the design team as well as other engineers, both with and without disabilities. The designers investigated the tradeoffs of each configuration of the cart's components and attempted to optimize the configuration for outdoor riding. The resulting configuration from the adult-size caster cart testing was transferred to a child-size cart taking into account the ergonomic differences in size, weight, and balance of the adult and child riders.

Design Criteria and Goals

The primary goals to meet the client's needs were:



Child-size Caster Cart

Safety:	The cart should be stable and controllable on slopes up to 1 in 4. The cart should have no protruding or sharp edges or other injurious components.
Performance:	The cart should maneuver well outdoors, indoors, and through standard door widths.
Ergonomics:	The cart should take advantage of a child's existing strength and balance to maximize performance.
Self-sufficiency:	The rider should be able to mount, dismount, and ride independently.
Social:	The cart should allow the rider to interact with children and adults.
Comfort:	The cart should accommodate custom seating cushions if necessary.
Durability:	The cart should require minimal maintenance and last for several years.

Discussion of Adult Caster Cart

The first adult-size prototype was made similar to the caster carts ridden by adults at Mexico's Project PROJIMO, a rural rehabilitation clinic. These carts are propelled by manually pushing the drive wheels, located in line with the rider's shoulders (similar to wheelchairs). The size, location, and type of drive wheels and casters for the adult-sized caster cart were adjustable and changeable.

Testing Methods and Results

The following criteria were used to choose the optimum configuration for the adult-sized cart for various terrains, and to choose the best compromise for maximum overall performance:

1. Amount of force needed to push on the wheels when turning the cart on grassy bumpy terrain.

2. Amount of force needed to push the wheels while going up hill, down hill, and level on bumpy grassy terrain as well as on smooth concrete.
3. Location of the cart and rider's center of gravity (cart's tendency to tip backward or forward).
4. Comfort with respect to drive wheel location and seat angle.

Due to time constraints of the semester, only subjective testing has been done on the caster carts to date. The subjective testing consisted of adult testers riding the cart over a predetermined course on bumpy grassy terrain and sidewalk. Each ride was timed, and independently evaluated by the criteria listed above. A front caster, rather than a rear caster, was chosen because it enhanced the mobility of the rider while riding the cart outdoors and over curbs. In the final configuration of the cart, the axle of the drive wheels was located just behind the cart and rider's center of gravity which put most of the rider's weight on the drive wheels rather than on the caster. With the final configuration, riders were able to push on the drive wheels to "pop a wheelie" and then maneuver out of a hole in the ground or over a curb. (A rear balance wheel was built on to the cart so that the rider could not tip over backward.)

Discussion of "Earth Scooter"

The optimization results from the adult-size caster cart testing were transferred to a child-size cart ("earth scooter") taking into account the ergonomic differences in size, weight, and balance of the adult and child riders. The "earth scooter" was tested with Sean throughout the various building stages. The final configuration of the "earth scooter" had similar maneuverability characteristics to the adult-size cart. The main difference between the carts was that the "earth scooter" had a plastic shell instead of a wooden one (for lighter weight and easier maintenance).

Conclusions

1. The use of the adjustable adult-size caster cart as an experimental tool proved to be valuable.
2. The drive wheels should be located close to the rider's sides and under the rider's shoulders to allow for maximum pushing force by the rider.
3. The tire width must fit the size of the rider's hand, so that the tires are easy to grip and push.
4. Of the currently used materials, plastic (polypropylene) provides a strong, lightweight, good-looking, and cleanable shell for the "earth scooter".
5. A lumbar support helps the rider when pushing on the wheels (especially uphill).
6. The "earth scooter" provides a relatively efficient, safe, durable, fun, and attractive means of transportation for a child.
7. A front caster, rather than a rear caster, enhances mobility on outdoor bumpy terrain.
8. The end result of this project is a step towards giving young children a custom-fit mobility aid to maximize individual mobility potential (both indoors and outdoors).

Future Work for the Project

1. Continue to have users with different types of disabilities test both carts.
2. Have the "earth scooter" analyzed by experts in the field of children's caster carts.
3. Research different types of propulsion, e.g. hand levers and hand pedals.
4. Make the carts more lightweight.
5. Find more ways of making the carts easily adjustable.

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Adult-size and Child-size Caster Cart

P4.17

BATH AID FOR BEGINNING SITTERS

Linda McEntrye, PT   Walter Krammer

INTRODUCTION

The majority of commercial bath aids for handicapped children offer support in a reclined posture. One aid that does allow upright posture is too large for many minimally to moderately involved pre schoolers who are beginning to sit. These children do not tolerate reclined positioning during bathing. Caregivers often express concern for safety due to the difficulty with handling their children for stability while simultaneously bathing them.

In Cincinnati during September 1987, a bath chair was developed by Linda McEntyre and Walter Krammer to address these needs for Elizabeth, a delightful 2 1/2 year old. Due to her delayed development secondary to cerebral palsy, Elizabeth was receiving physical therapy in her home from Linda McEntyre, private practice pediatric physical therapist. Elizabeth was just beginning to sit independently on the floor, with minimal supervision. She had difficulty achieving and maintaining adequate spinal extension and elongation of her abdominals, which limited her endurance and function in sitting. In the bath tub, buoyancy complicated her sitting. Stability and safety were a concern. Her family expressed a desire for a bath aid to free their hands for bathing. Elizabeth had experienced difficulties with ear infections, preventing bathing while supine on floor of tub. She was difficult to stabilize in seated position in the tub due to her muscle tone and patterns of movement. The family tried a number of infant aids, finding that they lacked adequate support or were too small. Additional aids, for infants and the handicapped population, were suggested and tried without success. The aid that came closest would require significant modification to be useful. A design concept was developed by the family and therapist. Walter Krammer an independent craftsman, who makes equipment for handicapped children, added his expertise to the project. Measurements and refinements to the design were compiled. A growth adjustable bath chair that provided support compatible with therapeutic goals, improved bathing safety and ease for caregivers resulted. This allowed supervised sitting in the bath tub.

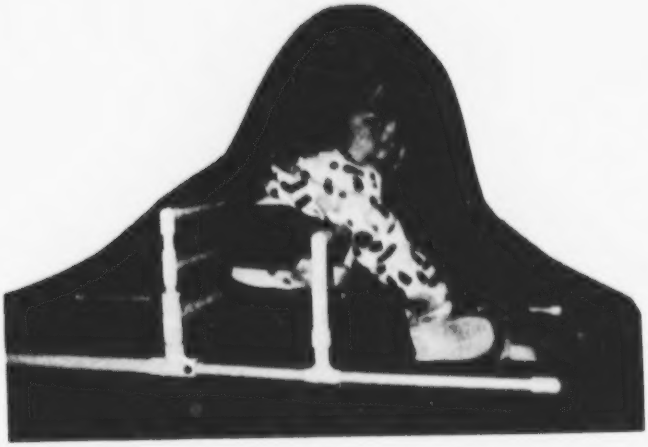
METHODS

Through handling Elizabeth, location of critical support was identified during several therapy sessions. Static support was simulated on floor and in tub. Family needs were defined. Measurements were taken of tub, heights, widths, and length required by Elizabeth now and projected for next few years. Contours were taken with a lead rule and traced. Relationship of supports regarding angle, heights and relationship to one another were defined. An aid was constructed by Mr. Krammer using water proof materials including PVC pipe, plastic and brass hardware. One anterior and two posterior supports were supported on height adjustable frames and mounted on a rectangular shaped length adjustable base. Width of base was determined by the tub width. Support components were molded to fit contours, flared to prevent pressure problems, and angled on support to fit Elizabeth's posture. The distance between anterior and posterior supports is adjustable with growth due to the relationship of the adjustments in the rectangular shaped frame and anterior frame for mounting anterior support. Some joints were glued. Height adjustment hardware chosen for noncorrosive qualities. This hardware included nuts and bolts in many locations and bolts alone in others where adjustments would be made regularly. Drainage holes allowed water to enter to anchor aid and exit to dry aid.

RESULTS

A bath aid was developed for Elizabeth. It provided:

1. Anterior support-to facilitate active spinal extension, encourage elongation of anterior trunk, offer stop to hip and trunk flexion, and freedom for arms and hands to manipulate and play with water.
2. Posterior pelvic support-to offer a stable base by anchoring pelvis posteriorly and laterally and to work in



conjunction with anterior support in the above functions.
3. Posterior trunk support-to provide a stop for excessive trunk extension. This component is removeable to allow entry into aid.
4. An aid that allows height adjustment for all supports, length adjustment to base frame and adjustment to distance between anterior and posterior supports.
5. An aid that is water proof and durable.
6. An aid to support beginning sitters while freeing caregivers hands for bathing and water play.

Elizabeth used this aid successfully. It allowed her hours of play in the bath tub, alone and with her brother. It assisted in developing improved sitting and increased use of both hands. Her family was better able to bath her safely and without risk of getting water in her ears.

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P4.18

WHEELCHAIR AMBULATION AID

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INTRODUCTION

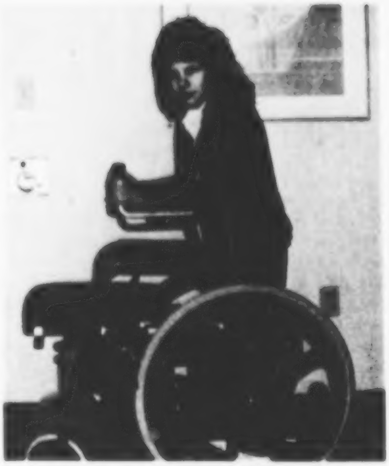
The wheelchair ambulation aid was designed in February, 1988, and completed in October, 1989 for Jennifer, a small statured, very active, 17 year old woman. She is impaired by profound bilateral sensori-neural deafness, ataxia, and epilepsy.(controlled with medication). Secondary to her sensori-motor dysfunction, she has developed a kypho-scoliosis, and eversion/pronation deformities of the ankles and feet. Despite surgical intervention, her scoliosis was progressing. Jennifer had been ambulating independently in indoor and outdoor environments, using a standard adult wheelchair for stability and balance. She ambulated by rounding her upper body forward, leaning her trunk against the back upholstery, and grasping the armrests to brace with extended elbows. Her gait was stiff, poorly graded, and poorly coordinated. Her stride length was significantly shortened, and her base wide. She demonstrated decreased hip and knee flexion in swing phase of gait, and genu recurvatum with everted/pronated feet/ankles in stance phase of gait. Normal weight shift was impossible. She demonstrated severely limited standing balance and decreased endurance. Her posture in ambulation was contributing to her deformity and, therefore, use of a wheelchair ambulation aid had been suspended. A variety of ambulation aids were tried without success, and Jennifer was frustrated by her lack of independence.

METHODS

Jennifer was observed using a standard wheelchair. Hands on evaluation was done to identify location and degree of support that would offer the most improved posture with the least support in standing, in gait, and when seated. Conditions were simulated with equipment and minimal hands on support. The following needs were considered when designing the device:

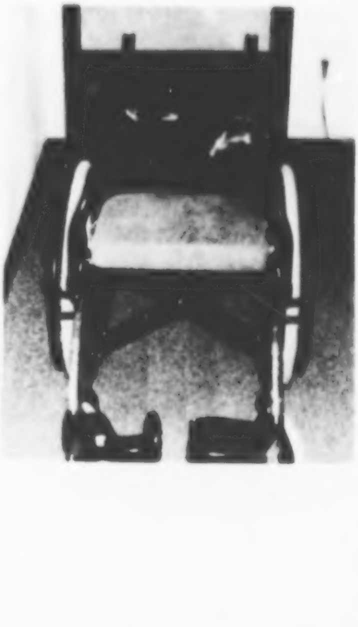
1. Portability: Must fold easily for transport in family car.
2. Durability: Must withstand varied terrain and weather.
3. Safety: Must lock to provide stability during transitions between sitting and ambulating. Must not obstruct the feet and legs in ambulation.
4. Maneuverability: Must allow trunk to be aligned with the axles and the hand grips placed forward near the front castors to permit mechanical advantage for steering and to decrease resistance to movement.
5. Mobility: Must support independent and assisted seated mobility and independent ambulation.
6. Enhance posture: Must minimize postures and movements that encourage deformity. Must encourage symmetry, functional alignment for standing, while ambulating, and sitting.
7. Independence: Design should permit Jennifer to manage adjustment of components independently.
8. Aesthetics: Must promote Jennifer's self presentation and aid in encouraging others to interact with her.
9. Reasonable cost: The cost should not exceed the price of a walker and wheelchair combined.

Commercial options were reviewed. The decision was made to modify a lightweight manual wheelchair. The Rally XL, with quick-release mag style wheels, antitip bars, swing-away footrests, and pull to lock brakes with extensions, was chosen. It offered the desired features and noncorrosive materials. The seat upholstery was replaced with a firm padded cushion and mounted with bipositional hardware. For ambulation, the seat is positioned forward of the cross frame, and, for seated mobility, against the push handles. The back upholstery was modified on one side with velcro enclosures so that it could be detached and fastened to the opposite backrest rail, thus allowing entry between the push handles without obstruction. Right angle aluminum extensions were indexed into the push handles to incorporate Otto Bock forearm supports and perpendicular hand grips. The push handles/forearm supports were secured at a fixed height and stabilized at one of the two desired positions with a quick-release pin.



RESULTS

A durable and aesthetically pleasing device, that met desired criteria, was constructed. With this device, Jennifer is afforded three levels of function: 1) independent ambulation indoors and outdorrs with good maneuverability and improved gait (longer stride length, narrower base, greater weight shift, less fixation in postures encouraging deformity and increased coordination and grading of movement), 2) independent wheelchair propulsion, 3) stability and postural alignment in sitting.
Her standing posture is improved (more erect, decreased recurvatum, narrower base). She can independently manage the adjustments required to make transitions between standing and seated postures, with the exception of turning the push handles. With practice, this may also be mastered. The device is easily transported in the family car. The cost was comparable to a manual wheelchair with seat and back inserts. Jennifer and her family were pleased with the outcome.



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Mona Hinton, referral source and Jennifer's PT
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P4.19

A TEST SIMULATOR FOR WHEELCHAIR (WC) PROPULSION

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ABSTRACT

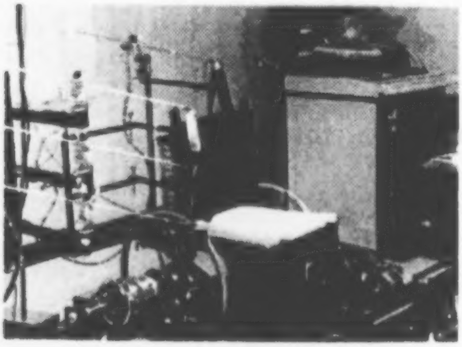
To understand the kinematics and dynamics of WC propulsion, joint and segmental motion must be monitored as well as changes in seat position and load.

To fulfill this requirement, a WC simulator and data acquisition system has been developed. The system uses direct measurement techniques to quantify movements of the trunk, shoulder, elbow, and wrist, in conjunction with changes in calibrated seat position, load, and speed variations. The system also allows for comparison between different modes of propulsion (eg. rims and levers). Data collected from this system allows a more complete description of WC propulsion biomechanics and may lead to optimized parameters which allow individualized WC prescription based on anthropometric dimensions of the user, physical characteristics of the chair, and level of disability. These data are also utilized to drive a computer based musculoskeletal and WC vehicle system model.

INTRODUCTION

The Rehabilitation Engineering Center of the University of Virginia has developed a computer aided test data acquisition and physical simulator system to test the WC propulsion process. This data collection is achieved through direct measurement techniques which allow propulsion, motion and resistance data to be synthesized through the computer program accompanying the WC simulator (Figure 1).

Figure 1: Wheelchair Test Simulator



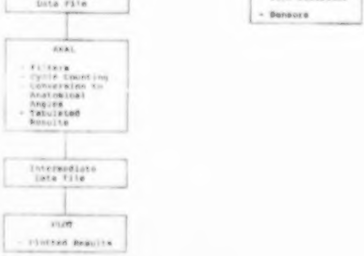
INSTRUMENTATION

The Wheelchair Simulator allows for subject testing in different seating positions. Variations can range through 35 cm in each of the three orthogonal (x, y, z) directions. A dynamometer simulates the effects of different terrains that a WC user may encounter, including lateral and frontal inclines. This is achieved through a range of loads and resistances resulting in variable speed and torque capability. This system also allows for the evaluation of different propulsion devices (eg. rims and levers).

To provide the computer with raw analog motion data, four motion sensors are attached to the simulator. Each sensor consists of three rotary potentiometers, which yield instantaneous spatial positions of the trunk, arm, forearm, and wrist in three orthogonal planes taken in relation to the hub. To supplement the spatial position data, an eight channel EMG data collection device has been mounted on the back of the seating frame to provide data about muscular activity pattern responses during the drive and recovery phases of propulsion.

The relative metabolic work and physiological energy cost of WC propulsion can be measured for varying conditions of propulsion. These measurements, along with work rates determined from dynamometer data provide the basis for calculating efficiency.

The following diagram indicates the flow of data through the computer system.



TESTS AND RESULTS

Preliminary studies have allowed direct comparisons for variation in seat position and method of propulsion. Figures 2 and 3 display plots which characterize the type of analyses that can be made using this system. These results were collected from a subject using both rim and lever propulsion with predetermined changes in seat position. All trials were performed at 3km/hr with a required total power output equivalent to 15 watts. Sample collection time was 4 seconds at a sample frequency of 10ms (100Hz). The plots shown represent two stroke cycles. The capabilities of the system allow an arbitrary number of cycles to be specified and analyzed based on the frequency and sample time selected. The distinguishing patterns of forearm flexion for rim and lever propulsion at a seat position of 13cm above and 21cm behind the wheel hub axis are presented in Figure 2.

An examination of the differences among corresponding variables for different propulsion conditions may provide a basis to identify the relationships among segmental motion and forces produced at the WC hub. EMG data for major muscle groups can be analyzed relative to complex motion patterns to provide a basis for the development of a model for accurate simulation of WC propulsion performance over a variety of conditions. The relationship between muscle activity and hub torque unique to lever and rim propulsion are evident in Figure 3.

Figure 2: Forearm flexion comparisons.

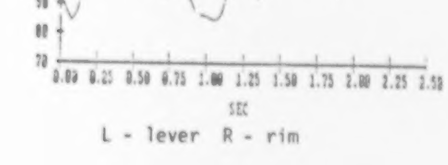
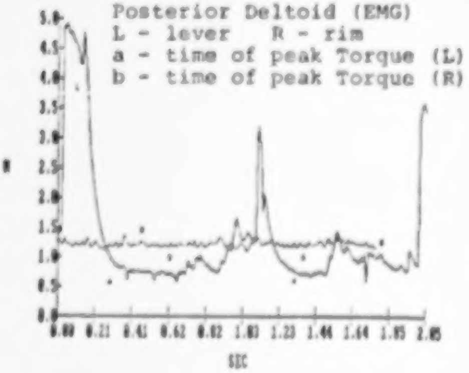


Figure 3: Hub torque and EMG patterns.



CONCLUSIONS

On-going research involving this system is directed towards not only understanding WC propulsion kinematics and dynamics, but also towards the determination of an ideal seating position for any one user. Level of disability and anthropometric dimensions are additional factors that will be addressed. The result will be a comprehensive software package with animation capabilities which the clinician can use in deciding the proper WC specification for the client.

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ACKNOWLEDGEMENT

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P4.20

SIMULATING WHEELCHAIR RACING

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ABSTRACT

This paper develops two nonlinear differential equation models for racing wheelchair propulsion. The first is for propulsion of a racing wheelchair over a flat surface (i.e. no road crown) while the second is for an intertial roller system. The necessary conditions for equivalence of the two models are presented.

INTRODUCTION

There have been several investigations into the physiological and physical factors which effect racing wheelchair propulsion. Racing wheelchair propulsion is of particular interest as by nature efficiency and optimal performance are desired. Although, wheelchair sports science and medicine has not reached maturity the need has already been expressed for modeling and computer simulation of racing wheelchairs and wheelchair racing [1]. The modeling of wheelchair racing may better be fascilitated in the laboratory where experiments can be controlled and repeated. Upon initial development of some models then verification can take place in the field. This requires the development of a simulator which can be related to wheelchair propulsion in the actual environment.

METHODS

A Model for Propulsion of a Racing Wheelchair over a flat surface.

A differential equation describing the motion of a racing wheelchair.

$$\begin{aligned} F(R/r_{a,r}) = {} & M\dot{v} + F_a + T_a/R_a \\ & + t_a/r_a + M_b/r_{a,} \\ & + M_b/r_{a,r} + F_R \\ & + F_r + I\dot{v}/R + I_r\dot{v}/r \\ & + W\sin\Theta(x) \qquad (1) \end{aligned}$$

The equations for air resistance.

$$F_a = c_0 v^2 \quad T_a/R_a = c_1 v^2$$
$$t_a/r_a = c_2 v^2$$

The equations for rolling resistance.

$$F_R = (W_R b_R/R)\cos\Theta(x)$$
$$F_r = (W_r b_r/r)\cos\Theta(x)$$

It will be assumed that the torques due to the bearing resistances (M_b, M_b) are constant.

After substitution.

$$\begin{aligned} F(R/r_{a,r}) = {} & (M + I/R + I_r/r_r)\dot{v} \\ & + (c_0 + c_1 + c_2)v^2 \\ & + (W_R b_R/R + W_r b_r/r)\cos\Theta(x) \\ & + M_b/r_{a,} + M_b/r_{a,r} \\ & + W\sin\Theta(x) \qquad (2) \end{aligned}$$

This can be simplified by using the gross air resistance and bearing resistance for the entire individual/wheelchair system. This may be of more practical value as the net effects are often easier to measure than specific effects.

Hence the reduced equation is written.

$$\begin{aligned} F(R/r_{a,r}) = {} & (M + I/R + I_r/r)\dot{v} \\ & + Cv^2 \\ & + (W_R b_R/R + W_r b_r/r)\cos\Theta(x) \\ & + W\sin\Theta(x) + K_3 \qquad (3) \end{aligned}$$

This equation is of the form.

$$F = K_1\ddot{x} + K_2\dot{x}^2 + K_3 + K_4\cos D(x) + K_5\sin D(x) \quad (4)$$

This is a nonlinear differential equation describing the interaction of a racing wheelchair with the environment.

The Inertial Roller Model:

The differential equation for rotation on an inertial roller system.

$$Fr_{a,r} = Iw + I_r w_r + F_a R + M_a + T_a + T(w,D,t) \quad (5)$$

The rotational model of the air resistance.

$$T_a = cw^2$$

The moment for rolling resistance.

$$F_a R = W_a b_a$$

This differential equation model in reduced form.

$$Fr_{a,r} = (I + I_a R/r)w + W_a b_a + M_a + cw^2 + T(w,D,t) \quad (6)$$

This equation is of the form.

$$F = k_1 w + k_2 w^2 + k_3 + T(w,D,t) \quad (7)$$

Using the well known identity $w = v/R$.

$$F = k_1 x + k_2 x^2 + k_3 + T(\dot{x},x,t) \quad (8)$$

This is also a nonlinear differential equation.

A Comparison of the Road/Track Model to the Inertial Roller System Model.

The validity of inertial roller system testing is dependent upon its similarity to racing wheelchair propulsion on the road or track. The differential equation models derived for the road/track and an inertial roller system are both nonlinear and have the same order. To initiate the same response the coefficients of the differential models, eqs. (4) & (8), must be set equal.

$$\begin{aligned} F &= K_1\ddot{x} + K_2\dot{x}^2 + K_3 + K_4\cos D(x) + K_5\sin D(x) \\ &= k_1\ddot{x} + k_2\dot{x}^2 + k_3 + T(\dot{x},x,t) \quad (9) \end{aligned}$$

with the physical restrictions: $k_2 \neq K_2$, and $k_3 \neq K_3$.

Therefore to reach equality constants c_2 and c_3 are defined.

$$k_1 = K_1,\ (k_2 + c_2) = K_2,\ (k_3 + c_3) = K_3$$

hence

$$T(\dot{x},x,t) = c_2\dot{x}^2 + c_3 + K_4\cos D(x) + K_5\sin D(x) \quad (9b)$$

For equation (9b) to be implemented it must be transformed back into its original coordinate system.

CONCLUSIONS

Racing wheelchair propulsion can be simulated in the laboratory using an inertial roller system with the use of a variable external load. This can be accomplished by using a simple D.C. motor/generator controlled by either a technician or more appropriately by a computer.

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P4.21

A SEATING/POSITIONING SYSTEM SIMULATOR

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In an effort to improve service delivery and product quality in the area of wheelchair seating and positioning systems, the Rehabilitation Technology Center - Indianapolis has developed a seating system simulator for use during the evaluation process.

The use of a simulator facilitates the decision making process by allowing clinicians to design a system during the evaluation which can be virtually replicated as the final product issued to the client. Experienced clinicians find their time more efficiently used, while persons new to the field can make appropriate choices based on the empirical information gained by using the simulator.

Various seats and backs can be quickly installed, ranging from flat plane surfaces to contoured and custom-molded cushions. Various types of commercial or custom postural support components, such as lateral trunk pads, lateral hip pads, head supports, etc., are added easily on adjustable hardware with a common interface. Supports can be placed with precision and stability, allowing clinicians to step back and observe results. Adjustments of the positioning components can be made quickly, based on observation and, when possible, feedback from the client. Tilt and recline angles can be incorporated and measured.

Once a seating system is designed, objective and accurate measurements can be taken from the simulator set-up, eliminating guesswork during fabrication, and allowing fittings to proceed more efficiently and with fewer suprises. This translates to lower costs and faster service for clients, as well as more efficient use of clinicians' time.

In designing the simulator, the goals were to make a device which would:

1. Be stable and safe.
2. Be mobile for transport to various locations.
3. Have a wide range of size adjustments for use with pediatric and adult populations.
4. Incorporate all parameters for determining system components, including angle and pressure measurements.
5. Incorporate a vacuum pump and dilatency bags for custom-molded systems.

The base of the simulator is built of structural aluminum, for strength with reduced weight. The back rest section is tubular stainless steel, and it moves forward and back on a roller track glide system.

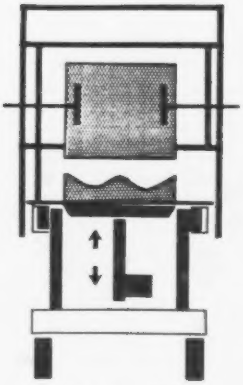
Electric linear actuators facilitate adjustment of the tilt and recline angles, and are used to raise and lower the seat height. Multi-adjustable hardware is used for installation of postural support components, and each component is fitted with a common interface so that they are interchangeable. Separate frames, with Pin Dot molding bags, can be positioned on the base to make custom-molded seats and backs, and a vacuum pump has been installed.

The range of adjustments is as follows:

SEAT INCLINE..............	35 degrees
BACK RECLINE..............	45 degrees
SEAT HEIGHT................	22" to 29"
SEAT DEPTH.................	8" to 24"
SEAT WIDTH.................	Up to 24"
TRUNK LATERAL WIDTH.......	6" to 22"
HIP LATERAL WIDTH.........	6" to 22"

LOWER EXTREMITY
ABDUCTORS..........6" to 22"
LOWER EXTREMITY
ABDUCTOR...........6" right or left
of center
HEAD REST..........8" right or left
of center

The simulator is used primarily at the Center, but is on casters and can be transported by van to complete on site evaluations. It is a valuable time saver, and minimizes technical errors and inappropriate choices, making service delivery more efficient and satisfactory for all concerned.



FRONT VIEW

Acknowledgements

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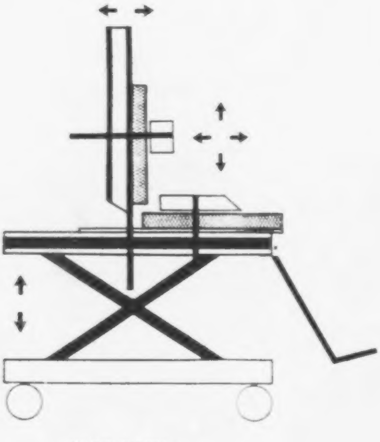

SIDE VIEW

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P4.22

TWO APPLICATIONS OF LINEAR (DRAWER) SLIDES IN SEATING

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ABSTRACT

The challenge of adapting or modifying commercial equipment to provide custom postural support systems in commercially available wheelchair bases requires innovative problem solving. Two such cases are presented, where linear slides are incorporated into the systems. The systems were designed utilizing dynamic system principles, then fabricated using available wheelchair parts and simple components available at any local hardware store. The use of readily available components allowed for cost effective systems and timely delivery. Both systems are currently in use.

INTRODUCTION

The Division of Developmental Disabilities is committed to interdisciplinary services, therefore, positioning needs are met by a team consisting of the Physical Therapist, Occupational Therapist, Rehabilitation Engineer, and engineering technical staff. At the Division, the majority of our inpatient population has positioning work completed during their stay. In addition, many of the outpatient population has minor positioning needs met during their clinic visit. In the cases presented, one drawer slide was applied during a 12 day inpatient stay, while the second was during an outpatient visit.

DESCRIPTION

Our first example of drawer slides in a seating system was for a child with severe and profound mental retardation and multiple fixed deformities, manifest as extension contractures of the hips, knees, and spine. She could tolerate a 25 degree elevation from the usual 180 degree reclined position. The postural support system was mounted on an Enduro manual recliner base. We utilized the recline function of the base to have three elevation points from 180 degrees to 150 degrees. The postural support system needed to be easily removable from the base and fold up, for ease of transport.

The postural support system consisted of a plywood sheet, upon which a contoured foam pad was constructed. The sheet and foam pad were hinged in the middle to allow for folding of the system. When in place, the plywood did not bend, even when the recline mechanism of the chair was used (recall that the client did not bend). We essentially had a 14 X 50 inch piece of plywood, that rested on the chair seat and back when the chair was 180 degree reclined. When the recline mechanism of the chair was moved to a position that would normally cause sitting up, the plywood was only in contact with the chair at two points; the top of the chair back and the front edge of the chair seat.

The mounting design called for a hinged component at the top of the chair back and a linear slide and rotational component attached at the front of the seat. Both points of contact also had to allow for easy removal. Trunion mounts (Pin Dot Products, Morton Grove, IL) and L-brackets were used to attach one end of the plywood positioning base to the wheelchair back uprights. For a broader line of contact at the seat contact point, tubing was mounted between the vertical sides of the seat base. This end of the positioning base was attached with drawer slides, which were in turn attached with Enduro seat clamps to the added tubing. Use of the trunion mounts and the seat clamps at the contact points allowed for ease of removal of the positioning system as necessary.

The second example of the use of drawer slides in a seating system, was for a C4-5 quadriplegic, who was positioned in a power recliner on an outdoor base. For back-up, the client had a standard manual recline chair. Both chairs had thoracic supports, rigidly attached to the chair back. These supports caused no problem in the power recline system, but upon reclining in the manual system, the upper body slid down, allowing contact of the thoracic supports and the axillas. It was noted that the gap between the seat and back increased from the fully upright to the fully reclined position. The client was seated on a Jay cushion, which was used in both chairs.

In the power recline system, the seat moved posteriorly during recline, producing an antishear seating system. We tried to duplicate this in the manual chair, with a linear slide component with stop on the seat and a cable component between the seat and back. Center mount drawer slides were mounted between the sling seat and a plywood base, upon which the Jay cushion was placed. The back uprights prevented the seat from sliding too far back. To maintain the fully upright gap, webbing was attached between the seat and back. With the seat on slides, the webbing pulled the seat posteriorly during reclining. The client's weight pushed the seat anteriorly when coming back to a more upright position.

CONCLUSIONS

While engineering dynamic system design can be utilized for seating modifications, fabrication must be both cost effective and allow for delivery in a timely fashion. The center mount drawer slide can be used as the linear slide design component in some applications. We estimated that linear slides available through medical equipment catalogs would cost $150 each. The slides described here were $8, and available at a discount store. Both of the clients described here were children, under 60 pounds. A heavier duty industrial slide may be needed for larger clients.

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P4.23

SPECTRAL ANALYSIS OF SITTING POSTURAL STABILITY

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INTRODUCTION

Maintaining a stable posture while seated is a prerequisite for upper extremity motor control. The acquisition of independent sitting has been extensively used as a developmental milestone to predict motor potential. Proper seating prescription can significantly contribute to improved functional ability of the child with neuromuscular impairments. Postural stability is important for successful school performance, wheelchair mobility, and the acquisition of occupational and recreational skills. It has been suggested that assuming an unstable seating posture can extend beyond discomfort and result in the development of skeletal deformities resulting in reduced physiological and neuromuscular functioning (2).

A primary objective of specialized seating systems is to improve postural stability of the trunk and allow for the increased use of arms and hands. Although the maintenance of postural stability appears to be an important prerequisite to many functional tasks, few techniques have been developed to quantify this ability.

Frequency characteristics of postural stability recently has been used to evaluate the standing stability of children (5) and adults (8). Several investigators have suggested that the frequency pattern obtained through such an analysis can reflect developmental level (7,9), different facets of neural control (3,1) and assist in the identification of neuromuscular impairments (3,4,5).

PURPOSE

The purpose of this paper is to report on a technique presently used in our laboratory to evaluate postural stability through an analysis of the frequency characteristics of the reaction forces applied to the seat surface.

INSTRUMENTATION

Instrumentation consisted of a Kistler multi-component measuring platform (9281B) mounted in an adjustable chair frame. The specific details of this instrumented chair has been previously reported (5). An eight channel charge amplifier was used to convert the output of the platform into proportional analog signals representing the seat reaction forces. Analog signals were input to an IBM-XT computer through a 12 bit A/D converter (Data Translation 2801). Software was developed using ASYST (Macmillan Software Company) data acquisition software.

Force data (F_x, F_y, & F_z) are collected over a user-designated sampling period. These data are stored in an array for subsequent analysis. Spectral data are calculated from each channel of force to provide the investigator with information regarding the frequency characteristics of the subject's seating stability. Quantification of force and frequency data includes the calculation of the following values:

RMS $_{\text{force}}$: a measure of variability of the force exerted on the seat surface in a specific direction. The mean of the force data is subtracted from the amplitude of each element of the array and the measure of variability calculated using the formula:

$$\text{RMS}_{\text{force}} = \sqrt{\frac{1}{n}\sum_{k=0}^{n-1} f_k^2}$$

where: n = Number of elements in the array

f_k = Amplitude of the force at the k element in the array (k=0 to n-1).

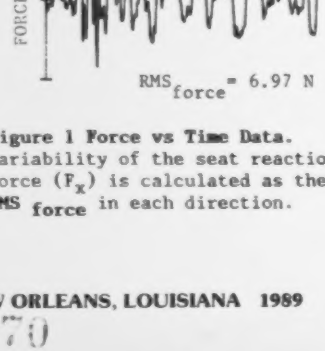

Figure 1 Force vs Time Data. Variability of the seat reaction force (F_x) is calculated as the **RMS** $_{\text{force}}$ in each direction.

$FREQ_{avg}$: frequency characteristics are calculated from the force in each direction using the Fast Fourier Transform algorithm. Data from the force spectrum were used to calculate average frequency of the forces. These values were calculated using the formula:

$$FREQ_{avg} = \frac{\sum_{m}^{n/2} f_m \; s_m^2}{\sum_{m}^{n/2} s_m^2}$$

where: s_m = Amplitude of the force spectrum at a specific frequency (f_m).

f_m = Frequency of the m^{th} element in the array

$S.D._{freq}$: a measure of variability of the frequencies contained in the force data. These values were calculated using the formula:

$$RMS_{freq} = \sqrt{\frac{\sum \left(f_m - Freq_{avg} \right)^2 S_m^2}{\sum S_m^2}}$$

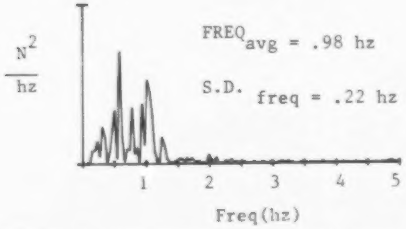

Figure 2 Frequency Spectrum of Force Data. **$FREQ_{avg}$** and **$S.D._{freq}$** provide the investigator with a measure of the mean of the spectral data and its concentration.

A rolling integration of the spectral data provides the investigator with additional insight into the power contained in the spectrum. Figure 3 is a graphic representation of these data graphically depicted.

SUMMARY

The methods presented in this paper are presently being used in our laboratory to quantify postural stability. A series of investigations are presently being conducted to determine the significance of these measures in quantifying various aspects of postural stability.

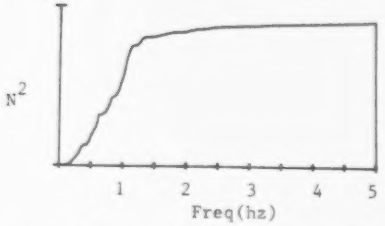

Figure 3 Rolling Integration of Spectral Data. The slope of the line represents the energy contained in the spectrum.

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P4.24

A NEW MODULAR WHEELCHAIR SEATING SYSTEM: DESIGN, PRESSURE TESTING, AND CLINICAL EVALUATION

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ABSTRACT

A new modular wheelchair seating system addresses the problems of pressure management and seating stability in a complementary fashion. Comprised of a firm, dynamic custom base and a gel top insert, this cushion provides good control of pelvic and lower extremity positioning, as well as excellent pressure relief. This paper describes this seating system and reviews studies of relative and absolute pressures and preliminary clinical efficacy.

INTRODUCTION

In developing seating for individuals in wheelchairs a number of objectives must be met, including pressure relief, seated stability, cosmesis, durability, and reasonable cost. Many of the challenges in this area arise when these objectives are contradictory or mutually exclusive Generally, those cushions which provide the best pressure relief (1) do not adequately stabilize the pelvis when there is severe neuromuscular dysfunction. Those which often provide the best pelvic control and stability (2) are often associated with unacceptable peak pressures over bony prominences. Carved foam cushions (3) have the advantages of light weight, low cost, and better pressure relief with adequate stability; however, their durability has in some cases been disappointing, and pressure relief often depends upon precise positioning. Custom-molded cushions remain the gest way to seat some individuals with severe deformities and/or spastitcity; however, their cost is high, their fabrication is specialized, ahd they do not allow for change in the individual.

DESCRIPTION OF DEVICE

The seating system is made up of three parts. The base of the cushion consists of an air-tight, soft, vinyl bladder filled with polystyrene beads. An adjustable valve at the anterior side of the base is attached to a small hand pump which is used to evacuate air from the bladder. As the air is evacuated the foam beads reversibly form a firm but resilient base which molds aroung the thighs and pelvic area, providing stability and control of the pelvis and limbs. Air can be let into the cushion at will, allowing a fully soft surface to re-form, or, if a small amount of air is added, a slight softening of the base will occur.

A gel pad is placed over this base, containing a substance with optimal viscosity to provide total contact without bottoming out. The cushion is covered with either a 4-way stretch Spandex cover or a stretch Patagonia cloth cover, to provide air flow and cosmesis and to protect the gel top.

The modular nature of this seating system allows for a number of variations in components and use. The base may be placed directly on the wheelchair sling seat, or may be set upon a solid insert. Depending upon the need for control of the limbs and increased relief over bony prominences, the amount of polystyrene bead material may be varied. The initial setup of the base by air evacuation may be done with the user sitting directly on the bladder, or may be done with the gel pad in place. The setup of the base may be done only once, or, if it is done with the gel pad in place, the base may be re-formed many times as desired for comfort throughout the day.

EVALUATION METHOD/RESULTS

Initial evaluation of the cushion studied static seated pressures of two spinal cord injured individuals on a sling seat, with a solid insert, forming the base with and without the gel pad in place, and with no cover, with the Spandex cover, and with the Patagonia cloth cover. There were no significant differences in static pressure between the two base molding methods; however, base molding shape was inconsistent with the gel pad in place, and therefore more subjects should be studied. Likewise, presence of either cover did not make a significant change in peak ischial pressures, which, in these subjects, ranged from 32mmHg to 60mmHg. Addition of the solid seat insert tended to make the pressures more symmetric and peak pressures were measured to be lower in one individual.

Preliminary clinical evaluation was done on four subjects. Three of these individuals were using a molded foam base cushion with gel insert and one was using a villous pneumatic cushion. Each subject rated the cushion on: (1) Comfort, (2)Body image/cosmesis (3) Subjective stability. All four subjects found the cushion to be superior to their present cushions in comfort. One of the four found cosmesis to be superior, while the other three found no change. Subjective stability was judged as improved in all four subjects, and the one who had been using a pneumatic villous cushion found stability to be markedly superior.

Clinical pressure evaluation was done using the subjects' usual pressure relief methods. Skin checks were done at 15 minutes, 30 minutes, 1 hour, and 2 hours. None of the subjects had any erythema using this cushion.

Additionally, it was found that in two subjects with moderate to severe spasticity, this cushion controlled pelvic and limb positioning better than their previous cushions. With addition of a solid insert it was possible to seat individuals with fixed deformities symmetrically and without unacceptable peak pressures. It was also possible with this cushion to obtain the effect of a wedge by shifting the beads forward before seating the individual and molding the base. This was helpful in those subjects with spasticity, both in effecting proper limb positioning and in maintaining proper anterioposterior positioning in the wheelchair.

CONCLUSIONS

This seating system offers a potentially viable solution to the problems of pressure relief and seated stability for a number of individuals with significant neuromuscular dysfunction. Its modular nature and flexibility allow the practitioner or the user to obtain custom seating results immediately and at a reasonable cost. Preliminary pressure evaluation suggests acceptable peak pressures for those requiring optimal pressure relief. Further studies indicated include: (1) evaluation of users with a wider range of seating problems, (2) clinical and laboratory measurements of more subjects with fixed deformities, (3) maintenence of posture, positioning, and pressure characteristics using a power recline system, (4) clinical skin tolerance under minimal pressure relief conditions, and (5) studies of the variables in this seating system with greater numbers of subjects.

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P4.25 INFLATABLE LUMBAR SUPPORT INCORPORATED WITHIN A CUSTOM BACKREST

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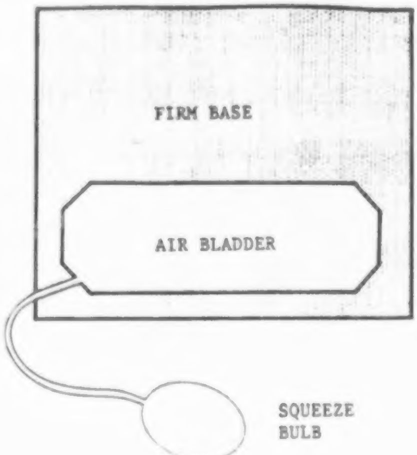
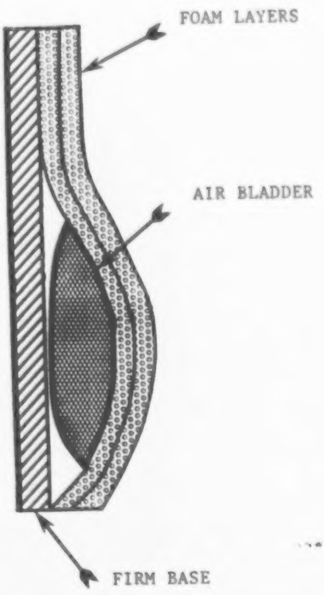
INTRODUCTION

Lumbar supports of various designs and construction have been used over the years to achieve functional postural alignment, and to aid in prevention of deformity. Frequently, this type of support has been omitted due to intolerance of constant support, or to problems with loss, misalignment or independent management of separate components. Use of an inflatable lumbar support, with manual inflation mechanism incorporated within a custom backrest, was explored with five clients. The diagnoses of these clients were: L2 paraplegia, T12 paraplegia, T6 paraplegia, C5 quadriplegia, and bilateral lower extremity amputee. Ages ranged from 20 to 55 years.



METHOD

The inflatable lumbar support was anchored at two points to the firm base, or bottom layer of foam, of a backrest with a variety of fasteners. Use of two attachment points allows expansion and contraction without binding. The firm base was notched at a specific location, dependent upon the individual client's need, to allow the tubing to exit the covered backrest. Additional layers of foam were then place on top of the lumbar insert. The lumbar support was incorporated into flat plane as well as contoured backrests. The inserts were covered with upholstery, using a vacuum forming process, and mounted in the various chairs in the customary manner. Wheelchairs ranged from lightweight folding and rigid frame chairs, to three and four wheeled power mobility bases.



SIDE VIEW

RESULTS

Clients report improved posture, ability to actively stretch into spinal extension, enhanced personal appearance, and increased comfort. Postural balance was maintained or improved. All clients were able to independently pump the bulb inflation mechanism. The air relief valve was modified for some of these clients. No problems have been reported, to date. Completed systems will be followed long term to determine durability and overall success. Clients with greater degrees of weakness might benefit from a switch operated electric pump. Designs for such a pump are in process.

ACKNOWLEDGEMENTS

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P4.26

SUCCESSFUL POWER MOBILITY BY BLENDING TECHNOLOGY WITH THERAPEUTIC PROGRAMING

Linda McEntyre PT

Robert David Neal

INTRODUCTION

Time invested in evaluation, simulation, and training can bring power mobility to increasing numbers of impaired children. Successful power mobility for Timmy Stephens was possible through these avenues. Tim is a bright, charismatic, youngster impaired by moderate to severe dystonic cerebral palsy. He had difficulty grading and isolating his movements. When he moved without guidance, movements were atypical and in extreme ranges, building considerable degrees of tone. This affected all his motor functions including mobility. Tim demonstrated difficulty with perceptual skills and visual motor function. During late fall of 1986 (age 6), evaluation of mobility aids for Tim began. Funding the recommendations took well over a year to accomplish. The chair fittings and training took place the summer of 1987 with final tray modifications and further training carried on throughout the 1987-88 school year.

METHODS

Tim's type and degree of impairment indicated that amubulation was not a likely possibility for mobility. He was unable to maneuver an manual wheelchair, therefore evaluation and simulation focused on power mobility. As it was essential that he be supported and his movement channeled to capitalize on functional movement of head and upper extremities, foam support components were used for simulation. Joy stick control was pursued as this provides greater and more efficient control. Location and configuration of the joy stick was explored using the atari. Additional support and guidance from tray and custom splint were also defined. All these components were incorporated into a simulated trial of a power chair. Time spent with simulation aided in bringing team members, including therapists, family and durable medical equipment personnel, together in support of recommendations.

All of the information gathered in the above process was incorporated into the following recommendations:

1. Invacare Jaguar with dufco controls (changed to Arrow controls when funding finally obtained) to provide a light touch joy stick and multiple adjustments for performance of chair.

2. Custom gently contoured backrest with OttoBock headrest and swing a way trunk supports. Split T foam seat with custom channeling of thighs, small integrated pommel and lateral contoured hip/thigh pads. Growth adjustment was incorporated by use of adjustable hardware for headrest, hip and trunk supports and by extending the seat beneath the backrest. The hip blocks were contoured around Tim's hips covering a portion of the lower backrest. A removeable block of foam filled the central space, offering the ability to inexpensively replace this support as hardware is widened, seat depth increased, and back height raised with growth. The lower portion of the backrest was not as thick, allowing the foam block behind the pelvis to be on same plane as rest of backrest. Custom footrest allowing channeling to guide posture vs restrain lower extremities. The footrest was also growth adjustable.

3. Custom tray to support remoted joystick and control switches. The tray was also an integral part of Tim's functional postural support, offering support to his forearms with shoulders in relaxed posture. Tim was able to grade movement better by sliding along the tray surface. A separate tray for school work was recommended as location of joy stick competed with work space.

The above components limit demands on Tim's motor system, increase his function, aid prevention of deformities and support therapeutic goals by guiding movements and posture within a functional range.

While waiting for the funding, work continued to address visual motor abilities, development of upper extremity splint (offering wrist extension and free movement of thumb and fingers with support by a distal palmar bar and dorsal forearm cuff) and overall sensori- motor development. Alternate positioning in pronestander and classroom

chairs was refined.

Once the chair was fitted and delivered, control and joy stick locations were further defined. Tim required precise location of joy stick in a range allowing graded movement in all four directions to as equal a degree as possible. It was most difficult for Tim to direct the joy stick to the left. He was unable to isolate wrist or shoulder movement to perform this task, compensating with elbow extension and shoulder protraction. This was also a weaker movement, therefore location allowing mechanical advantage for these movements was required. The joy stick was mounted just above the tray surface allowing Tim to slide has forearm along the tray surface to improve grading of, rate, and efficiency of movement. He was unable to contact a switch from above and exert adequate pressure to operate the remoted control switches. Controls were mounted on a sloped surface in limited area Tim could reach with any sort of grading. Switches most frequently used were located in most easily accessed locations. HI/LOW AND INDOOR/OUTDOOR controls were matched with terrains (outdoor, up ramp/carpet down ramp and indoor) and speeds were adjusted to meet these needs. A code sheet was attached to back of chair and to tray.

The training program, an integral part of Tim's success, incorporated visual motor training while static and while moving through space, spacial concept training using objects and movement in relation to objects, and overall responsibility with use of power wheelchair. Periods of independent movement were incorporated into early training sessions.

Structured time included games and structured activities to practice directed movement and work on visual, preceptual and judgement skills. Intervention was focused on safety, reminding Tim to use support system vs compensatory postures for stability, and some direct instruction. An attempt was made to avoid excessive use of cognitive control and to rely most on consequences of movement responses. Tim worked in a variety of environments indoor including gym, hallways, and classrooms, and outdoor including black topped and grassy areas. Training continued at school incorporating specific expectations and rules in that environment with his peers.

RESULTS

Tim is successful with independent mobility aided by a power chair, due to the combined efforts, persistence and creativity of many. Tim is independently mobile. You may see him at his brother's ball games, exploring on his family's small farm, on the playground, at the mall or the halls of school.

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Easter
Seal
Student
Design
Competition

Easter Seal Student Design Competition

I remember how excited I was when I entered my student project, "A Hand Powered Tricycle," at the 1978 Fifth Annual Conference on Systems and Devices for the Disabled. I was a student encouraged by Dudley Childress and Margaret Pfrommer at the Northwestern University Rehabilitation Engineering Program to get involved and explore the possibilities of technology applied to people's needs. After my experience in the design competition, I was hooked on rehabilitation engineering--the 1978 Conference opened my eyes to an exciting new field.

Eleven years have passed, and I am now a member of the judging panel to help choose five winners of the 1989 Easter Seal Student Design Competition--and I thought it was tough in 1978! I had no idea how difficult it was for the judges. Our panel selected five exceptional student projects, out of 34 entries, as winners to attend and exhibit their fine work at this 1989 RESNA Conference.

Each entry was evaluated on the following criteria:

1. Appropriateness to user's needs,
2. Innovation and creativity,
3. Manufacturability and marketing potential, and
4. Aesthetic values.

The National Easter Seal Society has made it possible for these creative students to attend this conference, and RESNA is grateful to the National Easter Seal Society for their support and enthusiasm. Everyone wins when we nurture fresh, new ideas, and encourage interest in this exciting field. We commend the efforts of all the students who worked long hours to develop quality design projects--they have all succeeded in the challenge of thinking and designing for the benefit of others.

Ken Kozole, BSME, OTR
Chair
Easter Seal Student Design Competition

SHIMMY DAMPER FOR WHEELCHAIR CASTERS

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ABSTRACT

Caster shimmy can cause wheelchair upset. A simple viscous grease damper was developed which fits within the caster housing and prevents shimmy at normal operational velocities. It enhances directional control without interfering with maneuverability.

INTRODUCTION

Wheelchair caster shimmy, or flutter, is a frequently cited problem. It is characterized by the caster assembly rotationally oscillating about the center line of the caster stem. When one of the two casters shimmies, the non-symetrical drag caused by its wheel tends to turn the wheelchair and can lead to injury-causing upset. This paper discusses a damper that was developed to prevent shimmy during normal operation.

BACKGROUND

All casters have a critical wheelchair velocity, V_c, at which excited shimmy is sustained. Reference (1) thoroughly analyzes the geometric, dynamic, and damping parameters that determine V_c. Its proposed use of a wider tire tread that is circumferentially grooved did significantly increase V_c. However, this solution is not applicable to the smoother riding balloon tired casters.

Various dry friction dampers which apply resisting torque to the caster stem have been used. However, when the friction torque is adjusted high enough to provide adequate damping, say for V_c's greater than 10 mph, the resulting static friction torque tends to lock in residual angular caster offsets, which in turn affects directional control.

The objective of this class project was to devise a practical damper which would not significantly affect normal wheelchair operation, and demonstrate its feasibility.

PROBLEM DEFINITION

The following performance and design objectives were chosen for the damper.

Performance objectives

(a) It needs to provide sufficient damping to attain a critical velocity, V_c, of at least 10 mph for the representative wheelchair, a balloon tired Quickie II (Manufactured by Motion Designs, Inc.) that was available for testing. (b) There should be no residual static friction torque. (c) The effect on normal wheelchair maneuverability should not be objectionable. (d) The performance objectives apply for an ambient temperature range of 40 to 95°F.

Design objectives

(a) It needs to have potential for easy installation on a majority of existing and/or new wheelchair casters. (b) It needs to be suitable for high production manufacturing. (c) The manufacturing cost is to be less than $6 to enable a market price of about $25 each. (d) It is to be maintenance free over the life of the wheelchair.

PROBLEM SOLUTION

Early on, the zero residual torque objective suggested that a viscous fluid be used as the damping medium. The problem solution centered on this assumption.

Preliminary analyses

The required torsional viscous damping coefficient (C_d) was determined by extension of reference (1) data, which was for a maximum V_c of 7.2 mph, to a V_c of 15 mph (a +5 mph safety factor target). The C_d required ranged from 2.0 to 5.8 in-lb/rps over the expected range of physical parameters.

Preliminary experimental work

It was apparent that to obtain such a high C_d in a compact device, a rather thick grease-like fluid would be needed. Silicone oil based damping grease was selected for its very high viscosity and relatively low visco-thermal coefficient compared to petroleum based grease.

Since grease is not tested for kinematic viscosity, experimental determination of its suitability was required. Bench tests of torque versus shear rate and temperature indicated that the most viscous available damping grease, made from 100,000 centistoke (cs) silicone oil, would meet the requirements of a small damper.

To measure V_c, the above mentioned wheelchair was rigged for towing by a manual transmission car. The tachometer measured the velocity within 0.5 mph. A "dummy" of three 50 lb. salt bags on the wheelchair seat applied the same 25 lb. load on the casters as did a 170 lb. person. Corresponding V_c measurements for the wheelchair ridden downhill and then towed verified the test set-up.

DESCRIPTION

Figure 1 shows the parts and assembly of the damper. It fits between the ball bearings within a standard Quickie II wheelchair caster housing. Figure 2 shows the damper installed. Tightening the stem nut secures the rotor to the stem. The vertical ridges of the housing prevent rotation of the stator.

The damper assembly is composed of only four different parts: The rotor which rotates with the stem, the stator which fits loosely within the housing, two plastic bushings to retain the grease and assure concentricity, and two retaining snap rings on the rotor.

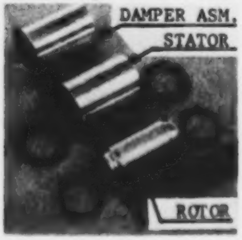

Fig.1 Shimmy damper parts and assembly

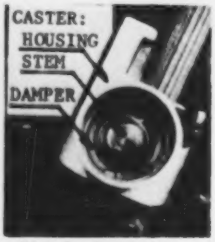

Fig.2 Damper in housing ready for upper bearing

The grease filled annular shear gap between the rotor and stator was initially 0.77in. dia., 1 in. long, and 0.004 in. thick.

TEST RESULTS/DISCUSSION

Without dampers, the tow test V_c was 8.2 mph. Installation of the above dampers, filled with 20,000 cs silicone oil based damping grease, increased V_c to 10 and 17 mph at 95 and 72°F. respectively.

The C_d's of these dampers was measured using a machine lathe and a "fish-type" force scale peripherally attached to the damper under test. The speed range was 0.7 to 4.2 rps. The resulting C_d's, based on a limited number of tests, ranged between 1.1 to 2.6 in-lb/rps at 95°F, and 1.7 to 4.5 in-lb/rps at 72°F. These are within the expected range for the V_c's experienced.

As expected, the residual friction torque was zero due to all parts being grease lubricated.

Three experienced wheelchair riders judged the maneuverability to be very acceptable. In addition, they appreciated the added control and safety benefit of the casters maintaining their straight ahead position when bounced off the ground.

The small size of the damper does lend itself to installation in most wheelchairs. Clips and/or adapters can be designed to restrain the stator.

COST

A preliminary manufacturing cost estimate for 1,000 dampers fabricated from stock aluminum tubing was about $9 each including tooling. Higher quantities and use of die castings and/or injection moldings should reduce the cost to under $6 each.

CONCLUSIONS

It is the author's opinion that the feasibility of this viscous grease shimmy damper was demonstrated, the design lends itself to low cost manufacture, and above all, it could improve the performance and safety of wheelchairs. Further development is warranted.

ACKNOWLEDGEMENTS

The encouragement and advice from Peter Pfaelzer and Ralf Hotchkiss of the S.F.S.U. R.E.T. Project staff, Jim Okamoto of Motion Designs, Inc. and Ken Hawkins - all wheelchair inventors and developers - is greatly appreciated.

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THE SEEING EYE CANE: A TECHNOLOGICAL AID FOR THE BLIND

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Abstract

In an attempt to aid the sensory needs of the blind, a project entitled "The Seeing Eye Cane" was proposed. The Seeing Eye Cane is a high-tech version of the standard cane, which gives the blind increased feedback about their environment. The Seeing Eye Cane provides three basic functions: 1) head-high object detection, 2) relative and absolute (North) direction indication, and 3) timing for crosswalk signals. The design of the cane provides a low-cost, lightweight, self-contained system that will assist the blind with with everyday mobility problems.

Product Purpose

The concept of the Seeing Eye Cane came from recognizing several problems of prime concern to the blind. First, the blind have decreased mobility because they are unable to detect objects in their immediate environment, especially at head level. While the standard cane provides the user with some information by detecting ground-level objects, the Seeing Eye Cane expands upon this feature by also providing detection of head-high objects. A second problem facing the blind is that they may lose their orientation because they cannot see physical landmarks which indicate direction and/or orientation. The Seeing Eye Cane contains an electronic compass which provides both relative (preset by the user) and absolute direction indication to the user. A third problem the blind sometimes encounter is difficulty in timing the periods of crosswalk systems. The Seeing Eye Cane responds to this problem by including an electronic timer in its design. In addition to these three problems, the design of the Seeing Eye Cane considers the overall needs of the blind by providing a system that is low-cost, light-weight, inexpensive, self-contained and easy to use.

Design Philosophy

To provide complex functionality in a compact size, the design of the Seeing Eye Cane centers around the MC68HC11 microcontroller, which controls the input from and feedback to the user, as well as the timer, compass and object detector subsystems. Input to the microcontroller is derived from an 8 X 1 key matrix which controls eight distinct functions: four timer settings, absolute North indication, relative direction indication, object detection and system reset. A software routine scans the input port checking for a key pressed and sends control to the appropriate routine when one is found. Output, or system feedback, is related to the user in one of two ways, auditory or vibratory response. The auditory (speaker) response consists of a tone used to indicate "time is up" for the timer, or a short beep used to indicate a function key was pressed. The vibratory (solenoid) response was chosen for frequent or continual feedback (so as not to disturb the user or others with constant auditory stimulation), such as in the case of the object detection and direction indication. The software that controls feedback is unique to the individual subsystem routines so that it will feel or sound different for each particular function.

In addition to the basic input and output systems, there are three main subsystems: 1) timer, 2) compass, and 3) detector. The first subsystem, the timer, is simply composed of a software module running on the MC68HC11 to gate 15, 20, 25 and 30 second time intervals. The second subsystem, the electronic compass, is more complex. It consists of amplified hall effect devices that are differentially coupled. The output is digitized by the MC68HC11 onboard A/D converter, and compared to either internal, or user set directions. The object detector, which is the third subsystem, is either a sonar or an infrared object detection system (both were considered in design but only the sonar system was implemented in the prototype) controlled by a software routine executing on the microcontroller.

Operation and Specifications

The Seeing Eye Cane resembles a standard cane in that it is the nearly the same size and shape, but it is unique in the fact the handle, which is hollow, houses the hardware required to run the system. The hardware consists of a number of digital and analog devices, including the MC68HC11, mounted on a 1" by 8" vector board, and five 1.2V NiCad batteries that supply power to the system. The hardware for the button matrix and feedback (speaker and solenoid) are also provided inside the handle.

Operating the cane is relatively simple. The user has only to turn on the power (via the power on/off switch), and press the button corresponding to the function of his choice (buttons are located on the handle). When a button is pressed, the cane emits a short beep which confirms a function was selected. If two or more buttons are pressed simultaneously, no beep will be emitted which means no function was invoked. The user has eight function options to choose from. If one of the four timer settings is chosen, a short beep will sound to acknowledge the selection and some time later (15, 20, 25 or 30 seconds later depending on which button was pressed) a tone will sound indicating "time is up". If the user wishes to enable the absolute compass, the appropriate button must be pressed, a short beep will sound to acknowledge the selection is valid, and then a vibratory response will be felt on the user's finger when the cane is held facing North. If the relative direction indication function is selected, the user will first hold the cane facing the desired direction, press the relative direction button, and wait for the valid selection beep. Now, when the cane is held in the preset direction, the vibratory response will be felt. If the user wishes to be informed of head-high objects, once again the desired button must be pressed, a short beep will be heard, and a vibratory response will be felt every time a head-high object is present. Each function will continue until completion (i.e. timer selections), another function is selected, or the reset key is pressed. This means that only one function can be selected at a time. A new function can be chosen or the current function can be restarted at any time by simply pressing the button corresponding to the desired function. If no functions are desired at a certain time, power may be turned off and the cane can be used as a standard one. It should also be noted that in order to supply the required power to the systems, the NiCads will need to be recharged overnight, with an expected lifetime total of 1000 charges.

Concluding Remarks

The Seeing Eye Cane is a powerful tool for the blind. It is an optimal solution to the problems facing the blind in that nothing has been compromised to give this degree of functionality including price (approx. $200), size (similar to a standard cane), aesthetics, and unobtrusiveness. By providing the blind with greater freedom, independance and security, this multifeatured aid will positively affect many lives by helping ease some of the everyday difficulties brought about by this physical challenge.

Our work was supported by the Multnomah School of Engineering, at the University of Portland, located in Portland, Oregon.

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25.2

THE "TALKING GLOVE": A SPEAKING AID FOR NONVOCAL DEAF AND DEAF-BLIND INDIVIDUALS

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ABSTRACT

A new two-way communication system is being developed to reduce the communication barrier between hearing persons and nonvocal deaf and deaf-blind people. A deaf person can "speak" to a hearing person by wearing the "Talking Glove," i.e., an instrumented glove which converts his fingerspelled words into synthesized speech. The hearing person replies by typing on a portable pocket keypad. This response is presented to a sighted deaf person on an alphanumeric wristwatch display or to a deaf-blind person on a mechanical braille display. The communication system has been tested by several deaf and deaf-blind individuals with encouraging results.

INTRODUCTION

While many deaf people communicate effectively with other deaf persons using sign language or the fingerspelling alphabet, confusion can arise when a hearing person, who does not know sign language, attempts to interact with a deaf individual who does not know the "oral" method, i.e., cannot speak intelligibly and read lips. For deaf-blind persons, communication can be even more difficult since they must exchange information tactually. These communication difficulties can adversely effect interpersonal relationships and vocational activities. Consequently, many deaf and deaf-blind people avoid situations requiring interaction with hearing persons, and as a result, often remain unemployed and do not fully participate in community life. Thus, there is a great need for a portable communication system which would permit nonvocal deaf and deaf-blind people to engage in conversation with others.

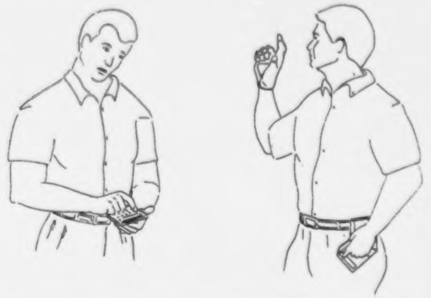
BACKGROUND

The most common ways a nonvocal deaf or deaf-blind person communicates with a hearing person who does not know sign language are via interpreters and notewriting. Although interpreters are effective in translating sign language or fingerspelling into speech and visa versa, they are often expensive and difficult to acquire on a moment's notice. Use of an interpreter also leads to a loss of independence and privacy. Notewriting is used by many deaf individuals to communicate with someone who is seated nearby, but it is awkward while walking, standing at a distance, and when more than two persons participate in a conversation.

A few devices have been developed to assist individuals with hearing or speaking difficulties. The most notable of these is the telecommunications device for the deaf (TDD). The TDD is not a hand-held device. It requires the deaf person to sit down and type on a keyboard rather than use a more *natural* communication method of the deaf community, such as fingerspelling or sign language.

METHOD

A system which provides expressive and receptive communication capabilities for nonvocal deaf and deaf-blind persons has been implemented. Although the goal is that the final system be portable, as shown in figure 1, some components of the present prototype are too cumbersome to be carried.



(a) Hearing person (b) Deaf-blind person

Figure 1 Talking Glove communication system

A block diagram summary of the communication system is shown in figure 2. The system consists of a Motorola 68HC11 single-chip microcomputer with various interchangeable peripheral devices that encode and display information. Each user can select the peripheral devices that best satisfy his individual communication needs. In the figure, the arrows denote the directions of information flow.

Figure 1 shows a deaf-blind person using the Talking Glove to communicate with a hearing person. The deaf person (Fig. 1b) fingerspells while wearing a glove equipped with uniquely designed strain gage flex sensors. The microcomputer receives finger joint angle information from the instrumented glove (Fig. 2, upper left). Eventually, this microcomputer will also execute the letter recognition algorithm, but presently it sends the joint angle information to a Zenith laptop computer for processing.

A neural network pattern recognition algorithm selects the most probable letter from a dictionary of previously stored hand formations that characterize the deaf person's fingerspelling "signature." When letters are spelled, the dictionary evolves as the recognition algorithm adapts itself to track variations in the letter formations. Once the letters of a word have been recognized, the entire word is spoken to the hearing person (Fig. 1a) via a DECtalk™ speech synthesizer. The deaf individual wears a small output speaker (Fig. 2, upper right) as a "speech pendant" under his shirt. In effect, the deaf person's expressive device is a Talking Glove.

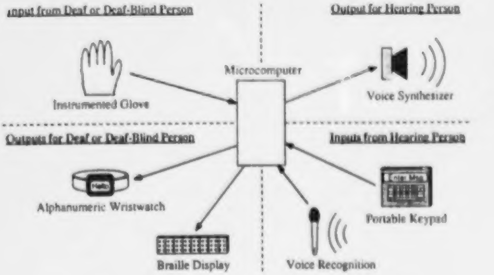


Figure 2 Communication System Summary

A hearing person replies to the deaf person by typing on the keypad of a Radio Shack pocket computer (Fig. 1a and Fig. 2, lower right). The small keypad can be carried by the deaf individual in a shirt pocket or purse and handed to the hearing person. The keypad has a liquid crystal display (LCD) that states the deaf person's name and requests a response from the hearing person. Information entered on this keypad is displayed for a sighted deaf person on a Seiko alphanumeric display worn as a wristwatch (Fig. 2, lower left). For a deaf-blind person, the response is presented on a specially designed mechanical braille display (Fig. 1b and Fig. 2, lower left). The braille display is worn on the belt for use while walking and talking, but detaches for desk-top use.

An IntroVoice™ voice recognition system has been tested as a replacement for the keypad in certain structured environments, such as at home or at work. Rather than type on the keypad, hearing individuals trained on this system can speak directly to the deaf individual. Speech is detected by a small, directional microphone (eventually to be incorporated into the deaf person's speech pendant) and converted into text by the voice recognition equipment (Fig. 2, lower right). This text is again displayed for the deaf or deaf-blind individual as was previously described.

Eventually, the microcomputer will be battery operated and worn on the belt like a Walkman™ portable radio. So that wires do not restrict the user, the microcomputer will also have radio or infrared wireless connections to the glove, wristwatch, speaker and keypad. In fact, several microcomputers may even share a common communication channel so that more than one deaf or deaf-blind individual could participate in the same conversation with more than one hearing person.

RESULTS

The prototype communication system has been evaluated by several deaf and deaf-blind persons, and has shown to be a practical communication aid. Interaction with these potential users has been informative, and many of their suggestions have been incorporated into the present design. Extensive clinical testing is planned.

DISCUSSION

The Talking Glove communication system presented here offers a natural, one-handed, portable method for deaf persons to generate synthesized speech. Besides producing speech output, the fingerspelling recognition system can also provide input to standard computing and telecommunications equipment. The focus of future research is to incorporate position and velocity sensors into the glove and recognize sign language signs. A sign language-to-speech communication system would be a very efficient means by which deaf persons could verbally express themselves.

CONCLUSION

The Talking Glove prototype provides a communication link between the silent world of nonvocal deaf and deaf-blind persons with that of hearing people. Rather than requiring deaf persons to learn to speak, the system allows them to quietly fingerspell and yet be heard. Since accepted communication standards such as fingerspelling, braille and speech are used, little training will be required. When the final system becomes portable, many people who now require a personal interpreter will achieve communication independence.

ACKNOWLEDGMENTS

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26.5

The Design and Development of a Synergetic Partial Hand Prosthesis with Powered Fingers.

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ABSTRACT

An externally powered partial hand prosthesis, based on the concept of powered fingers and synergy, has been developed for upper limb amputees. Designed for amputations at or more proximal to the level of the metacarpals. The hand's design and development are discussed.

INTRODUCTION

The number of functional partial hand prostheses presently available is very limited and those that are available take the form of body powered devices. These devices are driven either by the shoulder or the wrist. Both methods interfere with the residual motion of the arm due to the specific motions required to actuate the terminal device. Shoulder powered devices require a harness to be worn. They are frequently not efficient and a good cosmetic result is difficult to achieve. The wrist powered devices restrict the residual motion of the wrist to one degree of freedom (flexion/ extension), thereby decreasing the overall effectiveness of the amputee.

The wrist is used extensively in the positioning of the hand in space. A self-suspended, externally powered functional device would not interfere with the motion of the arm and it would preserve any residual motion of the wrist, greatly enhancing the overall function and cosmesis available to the amputee.

A review of current surgical/ prosthetic practices in partial hand amputations (1) indicated, in general, only persons with loss of thumb and all fingers at or proximal to the metacarpal joint required a functional prosthetic device. Typically, amputees without a thumb but with some fingers remaining are fitted with passive opposition posts against which objects may be grasped. The sense of touch inherent in the residual digits provides function that exceeds that of a functional prosthetic device.

No externally powered fingers are currently available for prosthetic applications. This, in the past, was due to a lack of drive systems that were small enough and yet capable of providing sufficient pinch force and speed. The feasibility of individually powered fingers developed with the advent of motors only 10mm in diameter (MicroMo MM1016) that are small enough to be placed within an artificial finger.

METHODOLOGY

At the beginning of the project the performance goals for each finger were set as follows; each finger should be able to develop at least 6 lb_f gripping force and travel with an angular velocity of 1.0 radian/sec or faster. The weight of each finger should not exceed 2.0 ounces.

Initial tests revealed that the MM1016 motor was capable of meeting either the speed or the force criterion, but was incapable of meeting both specifications simultaneously. The fact that the motor could meet the speed criterion at the expense of the force criterion (and vice versa for force) meant that the principles of synergy, as developed by this laboratory (2), could be used as a means of enhancing the performance of the overall system. In a synergetic system there are at least two motors; one delivering high force at low speed, and the other providing high speed at low force. The two motors working together in synergy provide what a single motor cannot.

The resulting design uses three motors, all MM1016's w/ 256:1 gearheads, one each in the thumb, index finger, and middle finger (See fig.1). In order to achieve the maximum pinch force, the thumb motor provides the speed, and the index and middle fingers deliver the force. The thumb was given speed so that the fingers will provide support for an object held while the hand opens, rather than have the fingers drop from under the object being grasped.

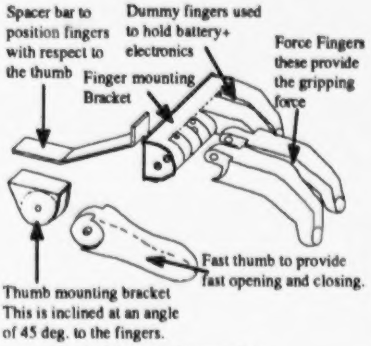
Spacer bar to position fingers with respect to the thumb
Dummy fingers used to hold battery+ electronics
Force Fingers these provide the gripping force
Finger mounting Bracket
Fast thumb to provide fast opening and closing.
Thumb mounting bracket This is inclined at an angle of 45 deg. to the fingers.

Fig. 1: Schematic diagram of the proposed hand.

The drive system for the fingers uses the a gearmotor along with a drive screw. The efficiency of the drive train (gearmotor and drive screw) is only about 55%. The actual pinch force per finger was found to be 8.5 lb_f using a 3-53 drive screw. The drive train is mounted in an endo-skeleton type armature (See fig. 2).

The drive system for the thumb uses the same gearmotor in combination with a 3:1 bevel and miter gear attached to a backlock mechanism. This provides an angular velocity for the thumb in excess of 2 radians per second and an excursion of around 3 inches (See fig. 3).

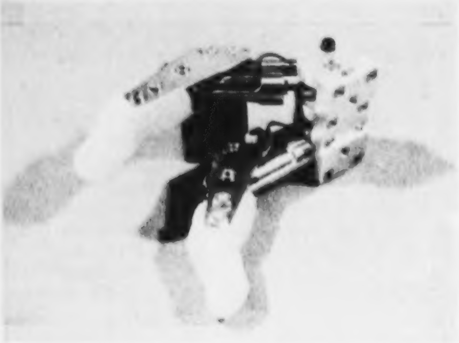

Fig. 2: Photograph of the force fingers showing the armature for mounting the gearmotor .

Keller, Taylor and Zahn (3) discovered that the most commonly used static prehension pattern is that of palmar prehension and the most common dynamic prehension was that of lateral prehension.

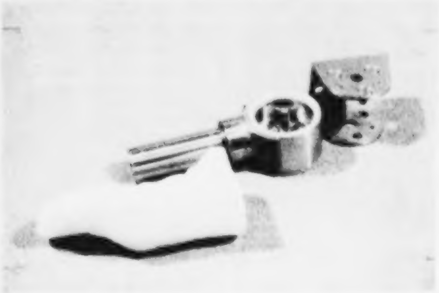

Fig. 3: Photograph of the fast thumb showing the gearmotor and backlock mechanism.

The thumb is inclined at an angle of 45 deg. to the palmar surface. This was done in order to improve prehension function. Lozac'h (4) showed that the function of a hand with a single degree of freedom thumb could be optimized if the plane of motion of the thumb is inclined at an angle between 45 and 55 degrees to the plane of the palm. This result is in agreement with those reported by Taylor (5) who concluded that "In palmar prehension, the thumb approaches the fingers in a plane inclined approximately 45 deg. to the palmar plane".

Inclining the plane of the thumb with respect to that of the fingers also maintains a cosmetic geometry for the thumb motion while providing a useable width of opening of the thumb and fingers. The dynamic cosmesis and width of opening considerations for an inclined thumb are dictated by the synergetic design. This requires the thumb to provide all the width of opening while maintaining a dynamically cosmetic geometry.

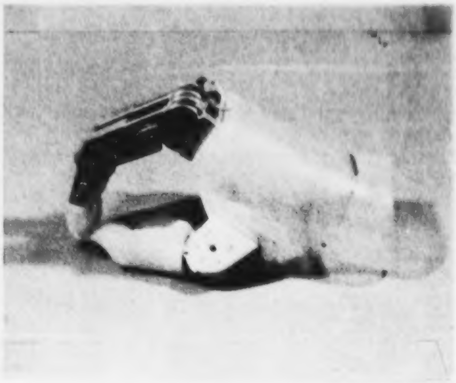

Fig. 4: Photograph of the complete hand.

The power source for the hand is a 9 Volt transistor battery that resides along with the control electronics in the dummy fingers or along the thenar eminence on the palmar surface of the hand. The preferred suspension of the whole hand would be to use a suction socket, such that any residual motion of the wrist could be preserved. Myoelectric or switch control can be used.

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INCREASED MOBILITY OF A POWERCHAIR

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The objective of this project was to provide the powerchair user the ability to climb curbs of up to 15 cm (6") in height. Powerchair users are presently restricted to relatively smooth terrain, not being able to negotiate obstacles which commonly interfere with their travel. Modifications had to be designed in an attempt to give the handicapped person the same amount of mobility that the general public enjoys.

The final design resulted in detachable additions that enable a powerchair to climb the required 15 cm (6") sidewalk curb. The design consists of three main attachments, one at each wheel. The attachments located at the rear of the chair had a different design than the one at the front due to different space and power requirements.

A prototype was built and successfully maneuvered over a six inch curb during testing operations.

DESIGN DEVELOPMENT

Mobility has always been a major obstacle that handicapped people have had to overcome. In the past few years powerchairs have been introduced which have allowed handicapped people to travel further distances with greater ease and in much less time. However, powerchairs are still not versatile enough to give the handicapped person the same sense of freedom that is enjoyed by the greater majority of the general public.

The powerchairs presently available are severely limited when travelling over rough terrain during outdoor use. Steep slopes such as hills and valleys, soft regions of sand and snow, and rocky or uneven surfaces (which encompass the majority of constraints experienced by powerchair users) including city streets, sidewalks, and steps of any kind, all present potential obstacles. Given the number of unfavourable terrains a powerchair user is likely to encounter on any given day, it becomes obvious that further research and development in the mobility aspect of powerchairs is needed.

The objective of this project was to enable a powerchair to climb a six inch step. After talking with a number of representatives from powerchair suppliers as to the uniqueness of the project, it was concluded that there had never been a three wheeled powerchair made which could climb six inch curbs.

A major part of the time directed to this project consisted of brainstorming in development of a solution to the problem while still complying with a number of limiting parameters; including size, weight, and cost.

A number of possible designs were investigated, each having certain restrictions. The use of larger diameter wheels raised the powerchair's center of gravity and made it unstable. A track system would require a redesign of the powerchair. Eccentric wheels require more torque than is available. A hydraulic system and a growing wheel mechanism were both considered too expensive. Therefore, a secondary wheel mechanism was chosen as the most viable solution.

The final design was decided upon and modified to attach to a Fortress 2000FS model powerchair. Use of a powerchair had been graciously donated by FORTRESS SCIENTIFIC.

FINAL DESIGN

The design consists of two identical mechanisms at the rear and a unique mechanism for the front.

Both rear mechanisms are activated at the same time by a single switch on the handle of the powerchair. The three way toggle switch acts as a forward-off-reverse device for both of the system's 1/30th hp motors.

As the output shafts from the motors turn, they rotate the secondary wheel mechanisms via the roller chain linking them. When the chair is raised to the desired height (variable for different size curbs) the motors are manually shut off, leaving the assemblies locked in their present position.

In this position the secondary wheel assemblies drive the powerchair. The secondary wheels are driven by the primary drive wheels through the friction force between them. The intermediate (idler) wheels allow the secondary driving wheels to rotate in the same direction as the primary driving wheels.

To lift the front of the powerchair a special addition was designed, different from that in the back, due to the space restrictions behind the front wheel.

The front lift assembly is driven by a separate motor, identical to those used to drive the rear secondary wheel mechanisms. The motor drives an attachment which rotates down onto the curb and lifts the front of the powerchair above the curb level.

The front lift assembly is again activated by a switch on the handle of the powerchair; the same type as the one used for the rear secondary wheel mechanisms.

THE LIFTING PROCESS

The front lift assembly is engaged when the front wheel of the powerchair reaches a curb. Once the front of the chair has been lifted above the height of the curb, the chair is driven slowly forward until the front wheel is entirely over the curb. The front lift assembly is then disengaged.

To complete the process of raising the powerchair onto the curb, the rear secondary wheel assemblies are engaged; lifting the rear of the powerchair to the required height. The chair is then driven forward until the rear secondary wheel assemblies come in contact with the curb and the primary driving wheels are over the curb. The secondary assemblies are returned to their disengaged position and the lifting process is complete.

In order to get down from a curb the same process is performed in reverse by initially backing up to the curb and then going over in reverse.

MARKETING ASPECTS

Considering the interest this project generated in the powerchair suppliers that were informed of it, the designed modifications are marketable.

For this project, the attachments were constructed within a given budget of $300. This was possible through the use of used and salvaged parts that were available as well as volunteered time for design and construction purposes. However, given a favourable market and mass production, the manufacturing cost of each lifting mechanism could be reduced to the point where the attachments would be economically viable for the powerchair user.

The aesthetics of the attachments could be improved by enclosing the powertrains of the lifting mechanisms (necessary for safety aspects as well) and painting the connecting arms.

ACKNOWLEDGMENTS

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